HE-3.3-10

EAS ACCOMPANIED BY GAMMA-FAMILIES AT MT. NORIKURA AND COMPARISON WITH MONTE CARLO SIMULATION

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ABSTRACT

The experimental data of EAS accompanied by gamma-families, with total energy greater than 10 TeV, obtained at Mt. Norikura, were compared with a Monte Carlo simulation with a rising cross section proportional to $E^{0.04}$ for the p-air inelastic cross section. It is found that the absolute intensity of size spectrum of such EAS is strongly affected by the primary protons intensity at 10^{15}~10^{16} eV region and the experimental size spectrum agrees with the simulated spectra for the p-poor (<15%) primary composition better than the p-rich (≳30%) one.

1. Introduction

The longitudinal development of EAS cores, especially at its early stages, depends on the collision mean free path and/or mass number of primary cosmic-ray particle in the atmosphere. The penetrated protons through the upper atmosphere without collisions or with a few semi-elastic collisions, even though their primary energies are a little low, are more advantageous to yield gamma-families at high mountains than the survival nucleons with normal fraction of energy in the normal EAS development. The inverse power form of the primary energy spectrum hastens this tendency. On the other hand, primary heavy nuclei are quite disadvantageous to generate gamma-families at mountain altitudes, because their primary energies are rapidly splitted into a lot of particles in the upper atmosphere due to their short mean free path and the plenty of initial constituent nucleons. Then, the observation of EAS accompanied by gamma-families with total energy greater than a certain value in an appropriate size range at mountain altitudes is nearly equivalent to observe EAS initiated by primary protons preferentially.

The combined EAS with gamma-families, which were obtained by the cooperative experiment between the EX chamber and the EAS array at Mt. Norikura (738 gcm^{-2}), were compared with the simulation with respect to the shape of size spectrum once at Bangalore (Nakatsuka et al., 1983). After that, the experimental data were reanalysed and a few combined events were added. The summary of the new results is presented in this Conference (HE-3.3-11). On the other hand, the simulation calculation was thoroughly renewed by employing the rising cross section, zenith angle distribution of incident particles and by extending the Monte Carlo calculation to lower energy than the former calculation by three orders. The results of new simulation are fairly different from the old one due to those changes, especially due to the last procedure described above. Then, we must abandon the former conclusions reported at Bangalore and the new results are presented here.

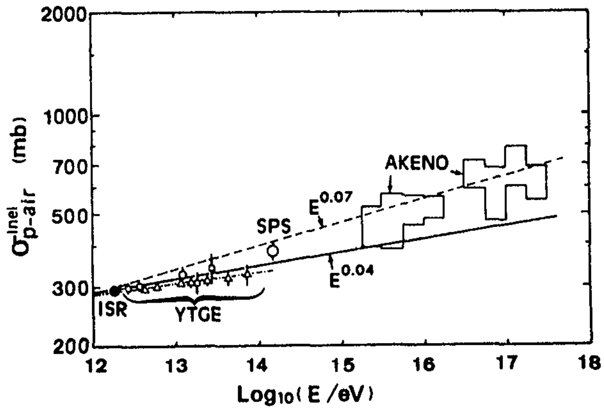

Fig. 1 Energy dependence of p-air inelastic cross section. $\bar{p}p$ accelerator data by ISR and SPS are transformed to p-air cross section. The solid curve with δ'=0.04 is assumed in the simulation. YTGE means the calculation by Yodh et al. (Yodh et al., 1983).

2. Assumptions and procedures in the simulation

First, the models about the hadronic interactions are summarized. The inelastic cross section of p-air collision has an energy dependence of a form E^{δ} instead of the constant cross section σ(p-air)=300 mb in the old model of simulation (Kasahara et al.,1979). When the energy dependence of $\bar{p}p$ cross section is expressed by E^{δ}, that of p-A cross section (A: mass number) is roughly given by $\propto(2E^{\delta}-1+A^{1/3})^2/(1+2A^{1/3}+A^{2/3})$ by a simple consideration that the increaese of nuclear radius is due to swelling of only surface nucleons. This function is approximated by σ(p-air) $\propto E^{\delta'}$ again. For instance, the values δ=0.073 ~ 0.11 representing the $\bar{p}p$ cross section from ISR data up to SPS data (Matthiae et al., 1983) are converted to the values δ'=0.044 ~ 0.068 for p-air collisions. In this paper we use a moderate rising cross section δ'=0.04 as shown in Fig. 1. The multiplicity of secondary particles satisfies the KNO scaling in all energy region but the mean multiplicity depends on collision energy in the form $a+b\ln s+c\ln^2 s$ with a=0.88, b=0.44 and c=0.118 as shown in Fig. 2, which is nearly equivalent to the old one. The inelasticity distribution is not changed from the old one. The rapidity distribution of secondary particles keeps nearly the form $(1-x)^4/x$ as in the scaling model although the cross section of QCD large p_T jets is added to the normal cross section in the new simulation. The calculation was done by the full Monte Carlo method until the energy of each shower particle becomes lower than 1 GeV. Hadronic jets in the iron EX chamber were simulated for the high energy hadrons arrived at the chamber and those which released electromagnetic energy greater than 3 TeV in the chamber were joined into gamma-families. We picked up only the simulated showers accompanied by a gamma-family with total cascade energy $\Sigma E_{\gamma,H}\geq 10$ TeV, $n_{\gamma,H}\geq 2$ for Emin=3 TeV, involving hadron initiated cascades, at the level of Mt. Norikura in accordance with the experimental conditions. And, the total number of shower particles (Ne) of them is calculated by connecting the one dimensional

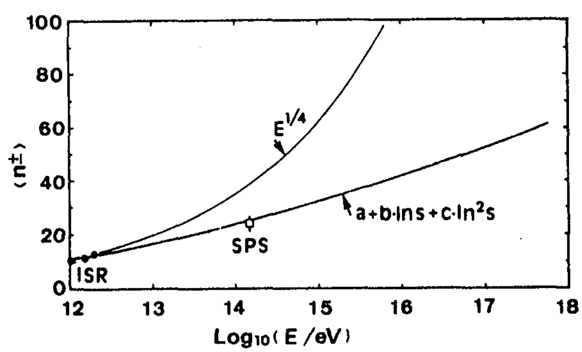

Fig. 2 Energy dependence of mean charged multiplicity. The solid curve is employed in the simulation.

cascade function to each shower particles generated by the full Monte Carlo method. The contribution of hadrons with energies less than 1 GeV is neglected. The conversion factor, i.e., primary energy per maximum EAS size is about 1.5 ~ 1.7 GeV/particle for the normal EAS with sizes from $5 \times 10^5 \sim 10^7$ in this simulation.

Second, the models about the energy spectrum of primary cosmic rays are described. The experimental data are briefly summarized in Fig. 3 (a). The total energy spectrum is represented by the solid curve which is smoothly connecting the Grigorov's data (Grigorov et al., 1972) and the air shower data at Akeno (Nagano et al., 1983). In this simulation are assumed two extreme models about the primary composition, especially about the fraction of iron nuclei. One is the p-rich spectrum as shown in Fig. 3 (b), where the fraction of iron nuclei is very small. Another one is the p-poor spectrum as shown in Fig. 3 (c), where iron nuclei are extremely abundant. The fractions of proton, helium and iron are tabulated at several energies in Table 1. The flat distribution of zenith angle with which the primary particles rush into the atmosphere is adopted instead of the vertical incidence.

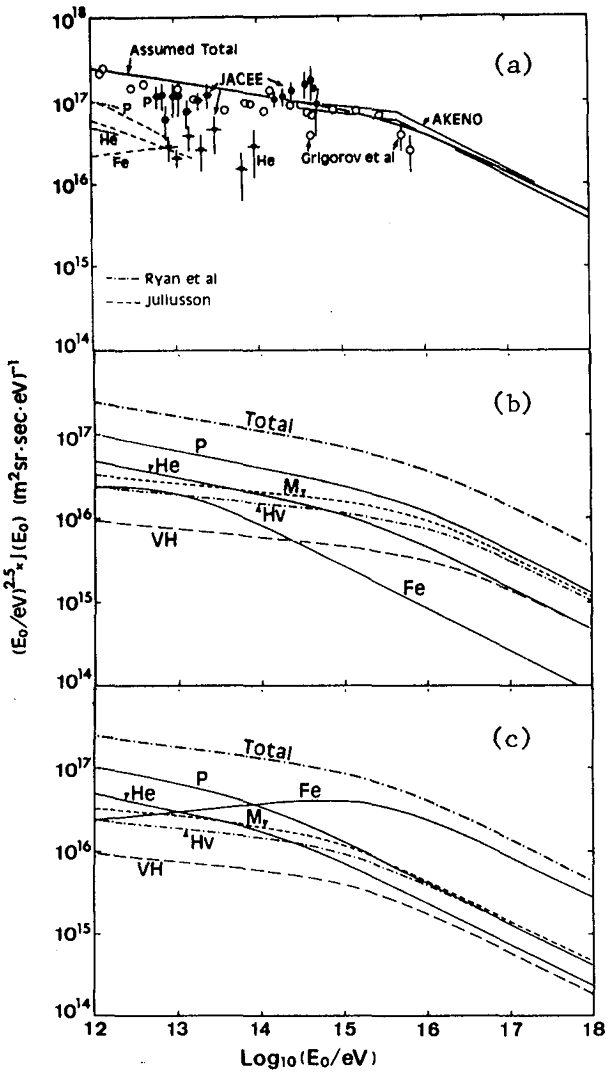

Fig. 3 Differential energy spectrum of primary cosmic rays.
(a); summary of experimental data. Some points are converted from integral form by Juliusson's way (Juliusson, 1975).
(b); p-rich primary spectrum assumed in the simulation.
(c); p-poor primary spectrum assumed in the simulation.

3. Results of calculation

The primary spectrum is cut at 10^{15} eV as its lower end in the calculation. This primary energy is corresponding to a mean shower size $\sim 6 \times 10^5$ at the shower maximum. Because EAS accompanied by such gamma-families we concern are generally at stages before the shower maximum and their sizes have a narrower correlation with primary energies than the general EAS, the size spectrum of them is surely free from the

Table 1

Energy	(eV)	10^{14}	10^{15}	10^{16}	10^{17}
p-rich	P	31.8 %	34.3 %	32.8 %	28.6 %
	He	17.3	15.7	12.2	10.7
	Fe	8.9	3.7	2.3	1.9
p-poor	P	25.4	14.8	10.0	8.1
	He	13.1	8.0	5.6	4.6
	Fe	30.0	45.5	58.5	61.4

bias due to the cutoff at the lower end of the primary spectrum for the size region Ne $\gtrsim 10^6$ at the observation level. Then, the comparison with the experimental size spectrum is done in this size region.

The number of primary particles sampled is 480 for the p-rich spectrum and 561 for the p-poor spectrum. Out of them the number of EAS accompanied by gamma-families with $\Sigma E_{\gamma,H} \geq 10$ TeV, $n_{\gamma,H} \geq 2$ for Emin=3 TeV is 45 events for the p-rich spectrum and 25 events for the p-poor one. The zenith angle distribution of these EAS are shown in Fig. 4 for the two cases of assumed primary spectrum. Both of them are represented by the theoretical curve with x_0/Λatt=7.0, which is consistent with the experimental data (Mitsumune et al, 1985). The integral size spectra of those EAS accompanied by gamma-families are shown by step lines in Fig. 5. From this figure we can see that the experimental data agree with the p-poor primary spectrum but not with the p-rich one.

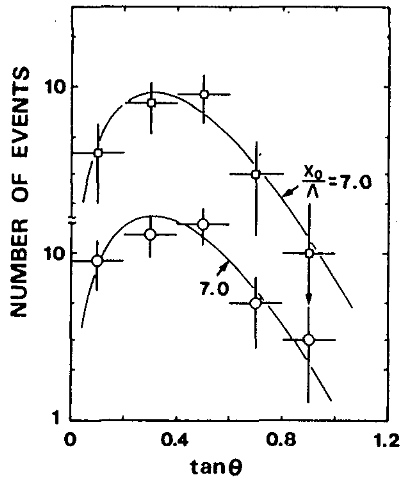

Fig. 4 Zenith angle distribution of simulated events with gamma-families. Open circles are for the p-rich spectrum and open squares for the p-poor one.

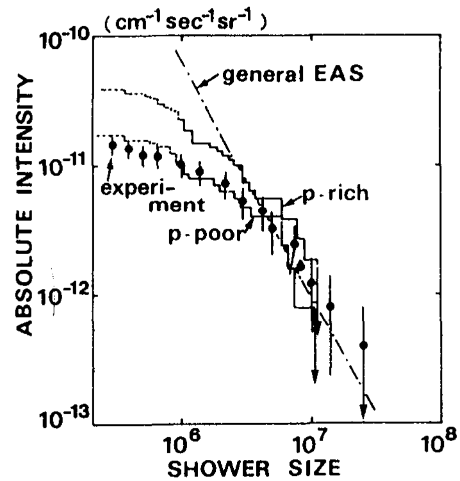

Fig. 5 Size spectra of EAS accompanied by gamma-families with $\Sigma E_{\gamma,H} \geq 10$ TeV, $n_{\gamma,H} \geq 2$ for Emin=3 TeV at the level of Mt. Norikura (738 gcm^{-2}).

4. Conclusions

Using the moderate rising cross section proportional to $E^{0.04}$ for p-air collision in the simulation calculation, the experimental size spectrum of EAS accompanied by gamma-famlies with $\Sigma E_{\gamma,H} \geq$ 10 TeV, $n_{\gamma,H} \geq 2$ for Emin=3 TeV agrees with the simulated result in the p-poor (<15%) case better than in the p-rich ($\gtrsim$30%) case.

5. Acknowledgements

The calculation was carried by the computer FACOM 380R of the Institute for Nuclear Study, University of Tokyo.

6. References

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