On the halo events observed by Mt.Fuji and Mt.Kanbala Emulsion Chamber Experiments

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ABSTRACT

The intensity of big gamma-ray families associated by "halo" is obtained from Mt.Fuji experiment (650 g/cm^2 atmospheric depth) and Mt.Kanbala experiment (515 g/cm^2). The results are compared with Monte Carlo calculation based on several assumptions on interaction mechanisms and the primary cosmic ray composition. The results suggest more than 3 times lower proton abundance among primaries than that of 10^{12} - 10^{13} eV region within the framework of quasi-scaling model of multiple production.

1. Introduction

Emulsion chamber experiments at high mountain altitudes are extending the concerned energy region over 10^{15}eV by the scale up of installations and accumulation of the exposure time. The integrated exposures have reached about 1000 m^{2}y and 300 m^{2}y at Mt.Fuji[1] and Mt.Kanbala[2], respectively, where the latter is already more than half of the former taking into account of the detection yield of the events. Some of the most energetic events ($\Sigma E\gamma$ >1000 TeV) observed by these experiments show a remarkable character of extremely high optical density on the X ray films at the gamma-ray family center, which we call halo. Some methodical problems connected to the energy estimation and the method of the analysis on the halo events are already reported in other papers[3),4)]. The responsible interaction energies for these events are estimated as 10^{16}-10^{17} eV. Since the extremely high energy density at the central part of the gamma-ray family is attributed to a number of energetic secondaries produced at the nuclear interactions in the atmosphere, the physical interest in the halo phenomena is connected to the feature of the multiple production mechanism in the fragmentation region at such a high energy and also to the primary cosmic ray composition, especially to the portion of protons. As already reported in preliminary works[4),5)], the experimental data show less intensity of the halo type event than expected one based on simple extrapolation of lower energy data on multiple production and primary composition. Some possibilities resulting to the decrease of the halo intensity are considered in this paper. Namely, the fast inceerase of interaction cross section, breakdown of scaling law as expected from the extrapolation of ISR-SPS[6),7)] results and possible change of the primary cosmic ray composition connected with the magnetic rigidity in the galaxy magnetic field are taken into account in the simulation.

2. Intensity of the halo events The number of big families with observed gamma ray energy more than 1000 TeV is 10 and 8 in Mt.Fuji and Mt.Kanbala experiment, respectively. The details of those events are described in ref. 2) and 5). The intensity of the halo events is examined in terms of the geometrical halo size defined as:

$$Smax = \int_{D>Dmin} dS \quad (cm^2) \quad , \quad Dmin=0.7 \quad (1) \quad ,$$

where Dmin is a given threshold for high optical density corresponding to the electron density of $3.24x10^6/cm^2$ in case of double side coating N type X ray films. The integration is carried out over the area where the net optical density exceeds given threshold Dmin. We can obtain the transition curve of the halo size measuring on X ray films of every layers of the chamber, then the maximum value is adopted as Smax. Thus defined halo size well describes the feature of the energy flow at the gamma-ray family center. The integral spectrum of the halo size Smax is shown in Fig.1 (Mt.Fuji) and in Fig.2 (Mt.Kanbala) together with the results of Monte Carlo calculation made by one of the authors (M.Shibata). The main characters of models used in the simulation are as followings.

PS,αS,CNOS : Complete scaling model in entire energy range with constant interaction cross section, assuming primary cosmic ray particles as proton, helium and CNO group, respectively (pure composition).
PC : Proton primary with CKP model[8)].
PSq : Proton primary with quasi-scaling model, where increasing cross section ($\sigma \propto E_0^{0.06}$) and breakdown of scaling in pionization part is taken into account to be consistent with ISR-SPS results as shown in Fig.3. In this model, x-distribution in the fragmentation part shrinks very weekly with increasing energy as shown in Fig.4.
MSq : The same interaction model as PSq but assuming mixed primary composition of heavy nuclei dominance as shown in Table 1.

Table 1. The primary composition in mixed composition model (in %)

E_0 eV <A>	P 1	α 4	CNO 15	LH 25	MH 35	Fe 56
10^{15}	10.8	4.4	6.9	22.9	3.0	51.9
10^{16}	7.3	3.1	5.0	20.3	2.6	61.6
10^{17}	6.0	2.6	4.5	19.2	2.5	65.1

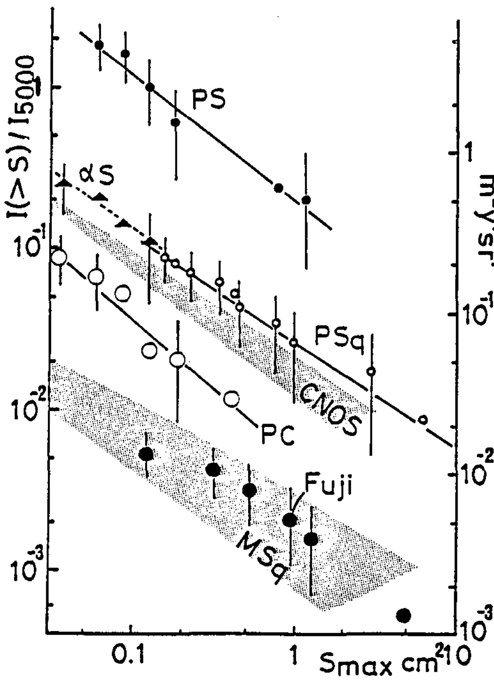

Fig.1 Intensity of the halo at Mt.Fuji. See eq.(1) for the definition of Smax.

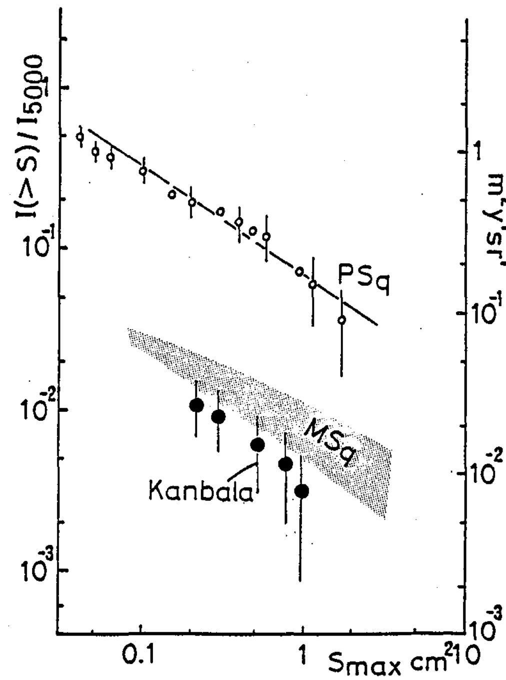

Fig.2 Intensity of the halo at Mt.Kanbala.

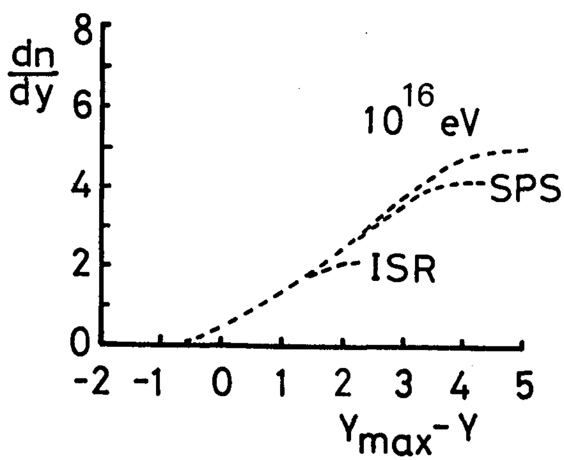

Fig.3 Rapidity distribution for quasi-scaling model.

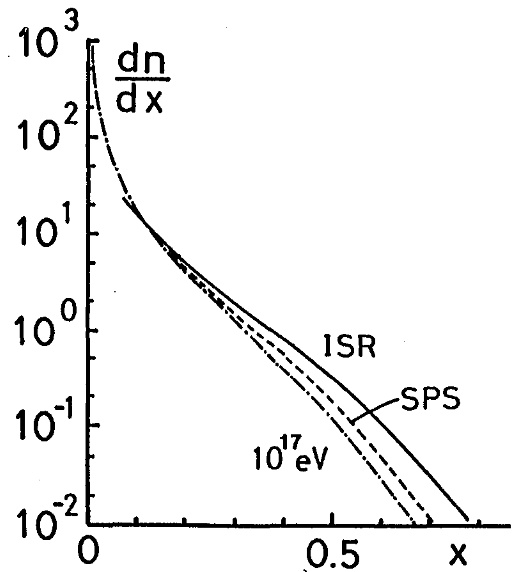

Fig.4 x-distribution for quasi-scaling model.

The intensities in Fig.1 and 2 are normalized to the number of primary cosmic rays at E_0>5000 TeV (left hand side scale) and to absolute intensity (right hand side scale) using I_{tot}(E_0>5000 TeV)=2.5/m^2y sr[9]. As is clearly seen from Fig.1, PS model is far from agreement with experimental data even if the portion of protons among total flux is considered. The quasi-scaling model with proton primary (PSq) still gives more than 10 times higher intensity. Therefore we can get agreement with experimental data within the framework of quasi-scaling model only when the portion of protons among total primary flux is less than 10 %, which is more than 3 times lower than the proton abundance known in 10^{12}-10^{13}eV region. The contribution of heavy nuclei for the creation of the halo events is expected to be very small from the results of αS and CNOS models (about 10 times lower efficiency compared with PS). In fact, the results of calculation with mixed composition described above (MSq:heavy nuclei dominance,quasi-scaling model) show most of the big events come from proton primary even its ratio is less than 10 % of total flux. (In present simulated statistics, only two events, one from helium nucleus and another from LH nucleus, contribute to the halo event among 25 observable events.)

Another possibility to interpret the low intensity of the halo events is to assume stronger breakdown of the scaling in fragmentation part than quasi-scaling model. But CKP type model is not suitable for this discussion because PC model in Fig.1 gives about 30 times less intensity than PS model. Therefore it cannot reproduce the halo intensity if the increase of cross section and primary composition is adequately incorporated.

Both results from Mt.Fuji and Mt.Kanbala experiments are in agreement with the discussion above within statistical error.

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