Emulsion Chamber Observations and Interpretation (HE 3)

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1. Introduction

The contributions to High Energy 3 session consist of 66 papers, which mainly deal with Emulsion Chamber experiments, related methods and theories. Hereafter emulsion chamber will be abbreviated as EC. The physical interest in this field is concentrated on the strong interaction at the very high energy region ($>10^{14}$eV) exceeding the accelerator energy, also on the primary cosmic ray intensity and its chemical composition.

The majority of the papers concern the experimental results from EC experiments at mountain altitudes or at higher levels using flying carriers. There are also some papers from hybrid experiment consisting of EAS arrays or calorimeters in addition to EC.

Those experiments observe cosmic ray secondaries and give us the informations on high energy interaction characteristics through the analyses of secondary spectra, gamma-hadron families and C-jets (direct observation of the particle production occuring at carbon target). The discussions are devoted to problems of scaling violation in fragmentation region, interaction cross section, transverse momentum of produced secondaries and some peculiar features of exotic events. Already a lot of discussions for these problems have been made in Kyoto, Paris and Bangalore ICRC, however, the statistics of experimental data are steadily increasing and the quality of simulation works are also progressing, reflecting the details of new accelerator results.

The following is the classification of papers for this talk.

Secondary spectra
Primary spectra
Gamma-hadron families
Halo events (Super high energy families)
Exotic phenomena
New technics
Cascade calculations, propagations
Hybrid experiments

Some important results are described below from each section.

2. Secondary spectra

The most basic data in EC experiments are gamma and hadron spectra, which reflect the interaction characteristics of hadrons in the atmosphere as well as the primary cosmic ray intensities. It is well known that the intensity of gamma rays at mountain altitudes is quite lower than the expected value from calculations[1] based on the scaling (or quasi-scaling) interaction model and energy-independent primary chemical composition with about 40 % of protons, as it is known at energies around 10^{12} eV.

Mt.Fuji collaboration (HE 3.1-3) presented those spectra from their

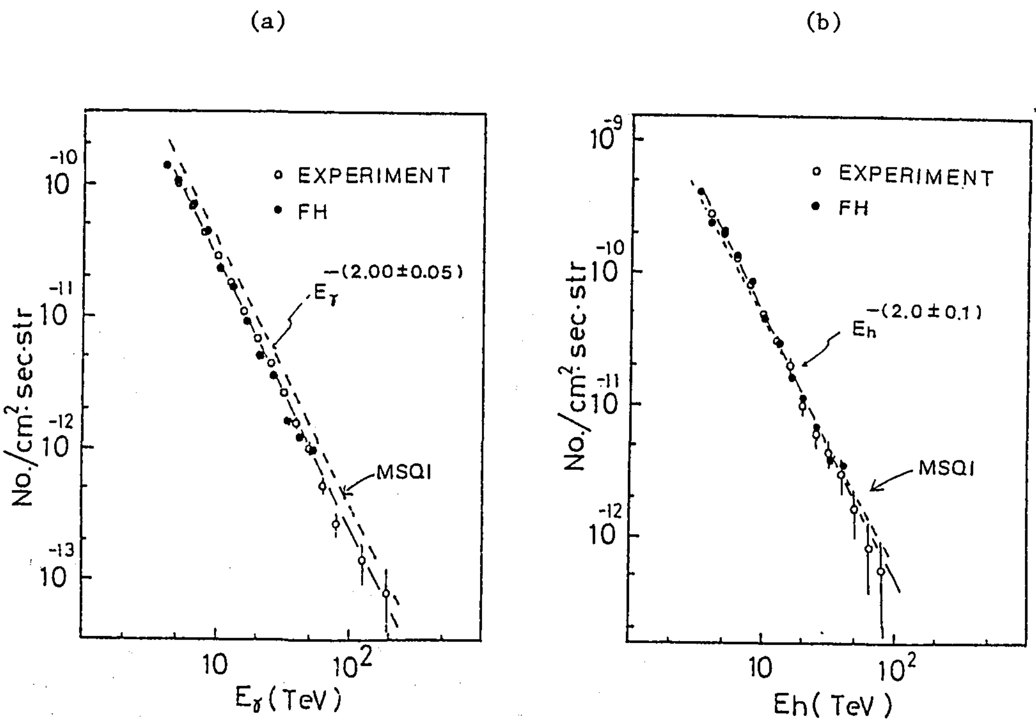


Fig.1 The energy spectrum of gamma-rays (a) and hadrons (b) at Mt.Fuji.

last exposure (Fig.1). The power indices of both components are the same within statistical errors, being 2.0. Both gamma and hadron fluxes are consistent with a calculation based on quasi-scaling model with heavy-enriched primary composition (Fig.2), where the total intensity is taken from Grigorov's[2] spectrum and the chemical composition is extrapolated from low energy data of 10^{12} eV range with an assumption that proton component has a knee around 10^{14} eV as suggested by the magnetic rigidity cut-off model of the cosmic ray propagation in the galaxy. Other components are assumed to have the knee at energies Z times greater, where Z is the atomic number. Such primary model gives proton-poor and heavy-enriched composition at energies greater than 10^{14} eV.

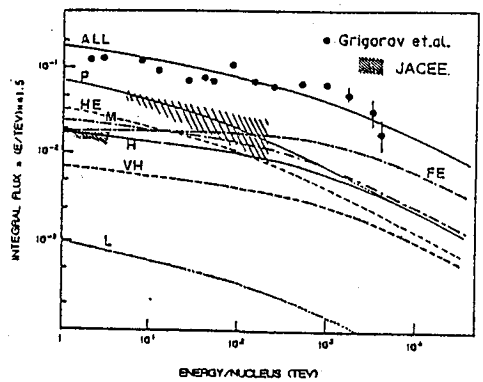
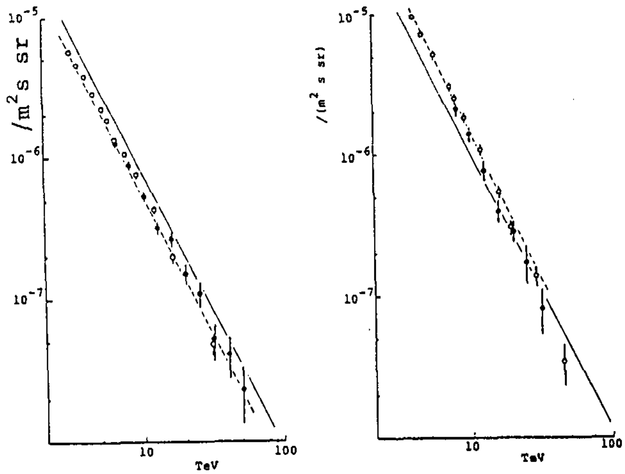


Fig.2 The heavy-enriched primary chemical composition assumed in calculations.

China-Japan collaboration also presented those spectra as shown in Fig.3 (HE 3.1-2). In a part of this experiment, iron is used instead of

(a) (b)



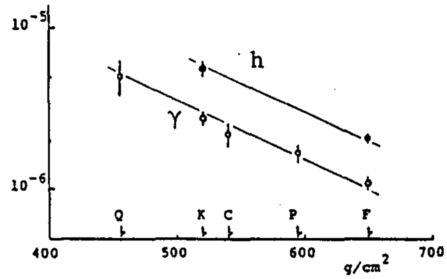


Fig.3 The energy spectrum of gamma-rays (a) and hadrons (b) at Mt.Kanbala.

Fig.4 Altitude variation of gamma-rays and hadrons.

lead and the result is consistent with that from lead chamber. Open circles and closed circles present the result from lead chamber and iron chamber, respectively. The slope and the intensity of gamma and hadron spectra are quite consistent with Mt.Fuji collaboration. The same Monte Carlo calculation as mentioned before can explain the attenuation of the secondaries in the atmosphere for world data, Qomolangma, Mt.Kanbala, Mt.Chacaltaya, Pamir plateau and Mt.Fuji. (Fig.4)

Cananov S.D. et al. presented hadron spectrum from Pamir experiment (HE 3.1-7). This new result (Table 1) is in a good agreement with other experiments.

Table 1. Hadron intensity by Cananov.S.D. et al.
(Normalized to Pamir level)

Experiment	$I_0(E > 5$ TeV$)/cm^2 s$ sr	The Slope
Mt.Fuji[3]	$(3.2 \pm 0.2)\ 10^{-10}$	2.0 ± 0.1
Mt.Kanbala[4]	$(2.9 \pm 0.1)\ 10^{-10}$	1.85 ± 0.1
Pamir Pb chamber[5]	$(1.9 \pm 0.4)\ 10^{-10}$	1.96 ± 0.1
This work	$(2.7 \pm 0.1)\ 10^{-10}$	1.9 ± 0.1

Summarizing the results of secondary spectra, all experiments are in a good agreement. The spectral indices of gamma and hadron component are about 2.0 in observed energy range of 10^{12} - 10^{14} eV. The absolute intensity and the attenuation in the atmosphere for mountain altitudes are well explained by a calculations with quasi-scaling model and heavy-enriched primary composition.

Quasi-scaling model assumed in these works means that the scaling law in the fragmentation region is not violated strongly, while the increase of the rapidity density in pionization region is taken into

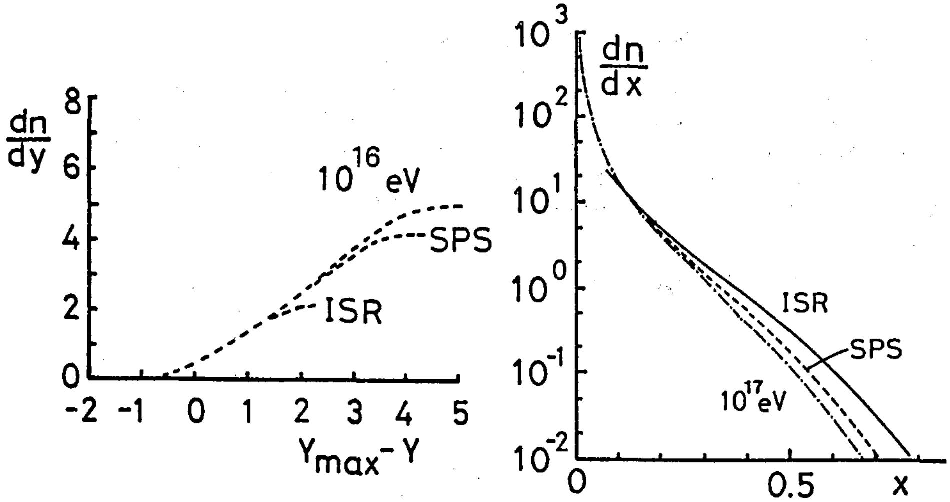


Fig.5 (a) Rapidity distribution and (b) x-distribution for quasi-scaling model.

account extrapolating ISR-SPS[6] results as illustrated in Fig.5 (HE 3.4-9) for rapidity and x distributions. The increase of proton-air cross section is assumed as $\sigma \propto E_0^{0.06}$.

However, this is not a unique interpretation of the secondary spectra because it is also possible to explain experimental data assuming stronger violation of scaling in the fragmentation region and energy-independent primary composition. This ambiguity cannot be solved when one treats only the uncorrelated secondaries. This problem will be discussed again in family phenomena.

3. Primary spectra

The observation of primary particles in the stratosphere is made by Mandritskaya K.V. et al. (HE 3.1-10). Results for 1-100 TeV range are shown in Fig.6 and compared with a mixed composition with following parameters, which are derived from the lower energy data by Ryan M.G. et al.[7], Simon M.[8], Ormes J.P. et al.[9] and Smith L.H. et al.[10] Helium and heavier components show good agreement with expected intensity. However, the proton spectrum shows steepening in 1-100 TeV range.

Another paper on the existence of the bump at 10^{15} eV in primary total spectrum was presented by Capdevielle J.N., Iwai J. and Ogata T. (HE 3.7-9)

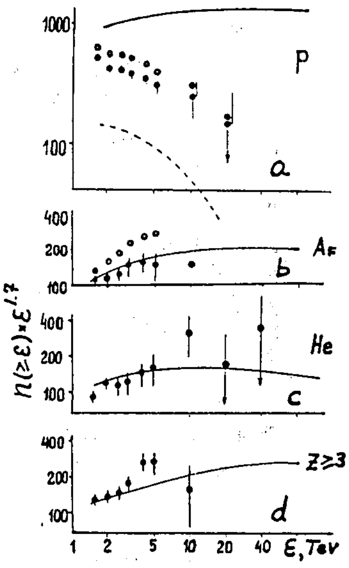


Fig.6 The primary spectra

from a compilation of Concorde[11], JACEE[12] and Japan Air Line experiments[13] as shown in Fig.7.

Summarizing the primary spectrum obtained by means of EC at energies greater than 10^{13} eV, still the situation is not clear, especially for proton intensity. A discrepancy is seen between the works by Mandritskaya et al. and the JACEE collaboration (Fig.8). One may question the statistical and/or methodical accuracy in these experiments. Therefore, at present, one cannot say definitely about the energy dependence of the chemical composition at energies greater than 10^{13} eV.

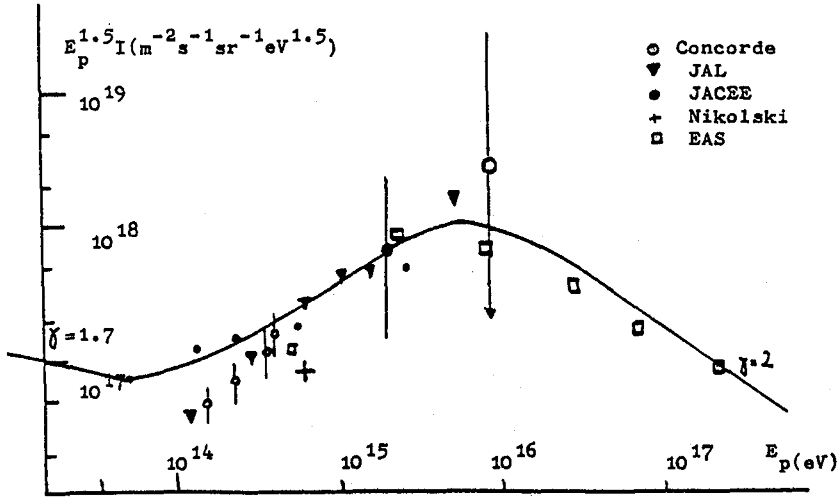


Fig.7 Primary total spectrum by Capdevielle J.N. et al.

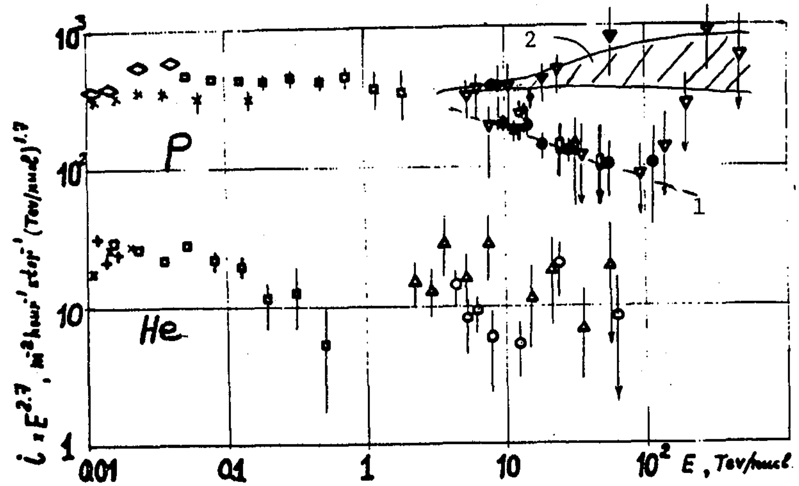


Fig.8 Comparison of proton spectrum between
1:Mandristkaya K.V. et al. and 2:JACEE collaboration.

4. Gamma-hadron families

Gamma-hadron families are generated by successive interactions of primary particles and their secondaries in the atmosphere. There has been a lot of works to account for nuclear-electromagnetic cascading effects in order to extract the characteristics of hadronic interactions from observed feature of gamma-hadron families. One of those approach is to compare experimental data with results of Monte Carlo calculations under various interaction models. Another is to try to eliminate those effects for individual events and trace back to the original interaction features. Such procedure was developed by many authors among EC experimentalists[14] and called 'clustering' or 'decascading'.

The paper presented by Mt.Fuji collaboration is using the first approach (HE 3.5-1). The intensity of gamma families is compared with results of calculations under various assumptions as shown in Fig.9, where M denotes Mixed composition, P - Proton primary, S - Scaling model, F - Fireball model of CKP type, which corresponds to the strong scaling violation in the fragmentation region, Q - that QCD jet effect is accounted, I - Increasing cross section and inside of the parenthesis is the knee energy of proton spectrum. The data are compatible with MSQI(100) model.

The energy weighted lateral spread of gamma families which reflect the transverse momentum of produced particles is compared in Fig.10, where T denotes the increase of mean Pt as $\langle Pt \rangle \propto E_0^{0.04}$, which does not seem to explain the data. Since family phenomena are very sensitive to the fragmentation region, it is suggested from this figure that the increase of mean Pt in fragmentation region is not remarkable.

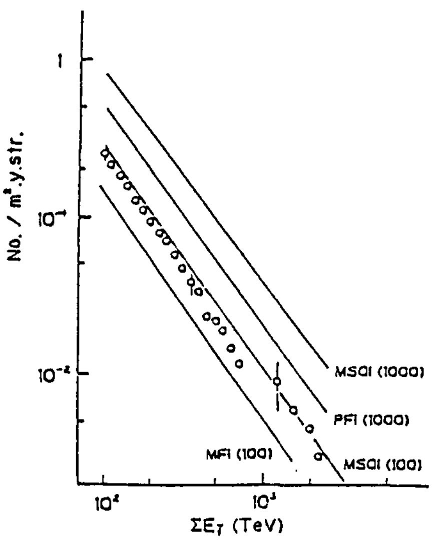


Fig.9

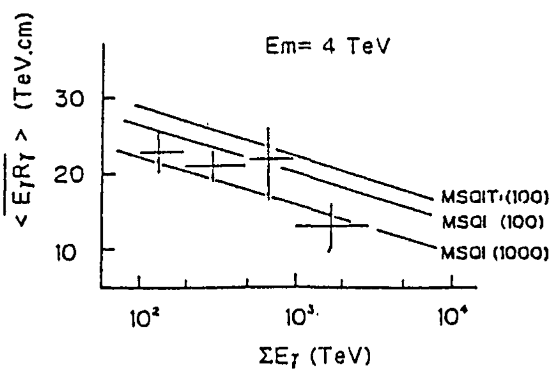


Fig.10

MSQI(100) model can also explain the binocular type events (with large lateral spread) as shown in Fig.11. The fraction of events with $\chi_{12}>100$ TeV cm is about 7 %. High multiplicity model does not explain these experimental data.

China-Japan collaboration (HE 3.4-2) presented a detailed analysis of an event KOE19 of the total visible energy 1537 TeV. The production height of this event is estimated from triangulation method to be less than 70 m. The clustering procedure lead to an interpretation of this event, in terms of QCD-jet, as 5-jets event with quite small sphericity (0.0074).

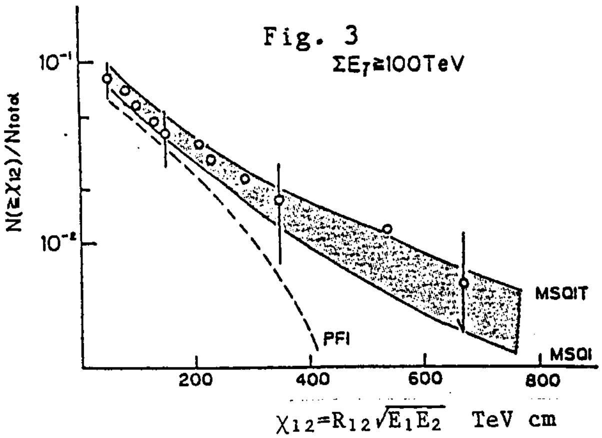


Fig.11

Navia O. and Sawayanagi K. made a cluster analysis on gamma families for Chacaltaya EC data (HE 3.2-1). From B-ER correlation, where B is the asymmetry parameter defined by A.Kryś et al.[15], they pointed out the existence of multi-jet with symmetrical structure. When the lateral structure of family is symmetrical, B is close to 1 while it is close to 0 if the showers are grouped along a straight line. Gamma families are classified by energy weighted lateral spread, then B distribution is shown in Fig.12. In the widest class of families, one can see a peak close to B=0, which can be understood as binocular type events. However, there are non-zero distribution in symmetric region too. The authors conclude that for those events the <ER> values are as large as for binocular events but the number of jets is much greater, which makes the structure more symmetrical.

Azimov et al. presented a similar analysis for Pamir EC data using a symmetry parameter, α, instead of B. The definition is just opposite than of B, α is 0 for symmetric case and is unity for asymmetry (HE 3.7-1). They also showed the existence of wide and symmetrical families. Their explanation of these families as generated by heavy primary nuclei is based on the comparison of experimental data with calculations using a quasi-scaling model and mixed primary chemical composition.

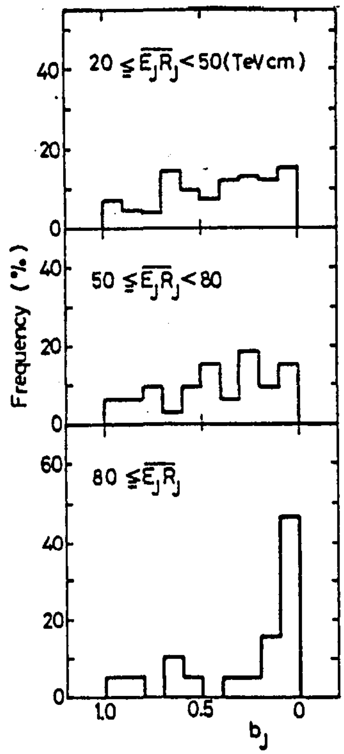


Fig.12

Therefore, the events with large lateral spread cannot be directly connected with QCD-jet or large Pt phenomena but most of them are probably generated by heavy primary nuclei. The event KOE19 reported by China-Japan collaboration does not belong to such cases because of small lateral spread corresponding to the low interaction height. However, we need more statistics to draw a picture of multi-jet production process at very high energies.

In a paper presented by Pamir collaboration, an investigation was made for the ratio of energetic hadrons with no visible hadron accompaniment to the total hadron intensity (HE 3.1-11). It is shown that this ratio is much higher than the predictions of scaling models as shown in Fig.13. The considerations on the increasing interaction cross section or the primary chemical composition are not successful in explaining the experimental data. The violation of scaling in fragmentation region is required to explain this discrepancy, according to the authors.

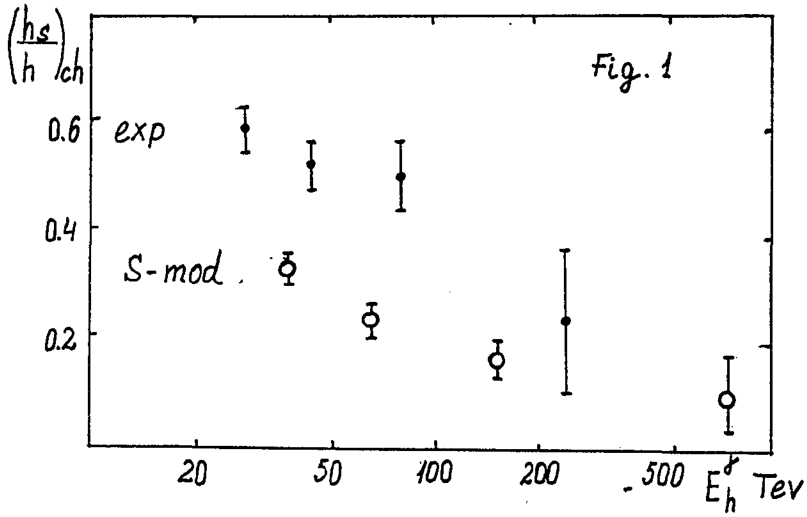


Fig.13 Single hadron ratio to total hadron intensity.

T.K.Gaisser ,T.Stanev and J.A.Wrotniak made a Monte Carlo simulation on this problem and showed the sensitivity of single hadron intensity and gamma-hadron ratio to the different interaction models (HE 3.4-7). Their results show that single hadron ratio to the total hadron intesity by Pamir experiment seems to be explained within a statistical error. However, Gamma-hadron ratio of Pamir experiment cannot be reproduced by quasi-scaling model. Possible explanations by authors are,

1. breakdown of scaling in fragmentation region,
2. there are more hadrons produced than they assume,
3. the underestimation of gamma ray energy or more probably the overestimation of hadron energy.

Summarizing the papers on gamma-hadron families, there is still an ambiguity in interpretation of the experimental data in 10^{14} -10^{15} eV range. The global features, like family intensity and lateral spread, may be explained by the interaction mechanisms extrapolated from the accelerator results with only very slight scaling violation in fragmentation region with an assumption of heavy-enriched primary composition. The events with large lateral spread and their symmetry structures are also explained within those framework, as it is shown in clustering analysis. If the above explanations are valid, then the transverse momentum in fragmentation region seems to remain almost constant.

On the other hand, another result reported by Pamir collaboration on 'the high ratio of the energetic hadrons with no hadron accompaniment to the total hadron intesity' is not explained by above mentioned point of view. This can be explained by nuclear interactions, where no secondary particles have sufficiently high energy to be detected. Then, only survival hadron is detected with no visible accompanying particles. Such situation would be explained by strong breakdown of scaling in fragmentation region and/or the change in inelasticity with energy. Mt.Fuji experiment also found the excess of single hadrons, but less one compared to the results of Pamir experiment, being about 10 %[16]. They claim this excess would be attributed to a scanning inefficiency for low multiplicity events. On the other hand, the result, which Pamir experiment concludes to be in contradiction with scaling model, is successfully explained by the work of T.K.Gaisser et al. According to their calculations based on quasi-scaling model, also taking into account of the design of the Pamir chamber, the result does not contradict with experimental data within the statistical accuracy. This problem needs more investigations both in experiment and calculations to clarify the sensitivity to the interaction mechanism and also to the experimental bias like energy determination, scanning efficiency for accompanied particles and so on.

5. Halo events

Some of the most energetic families show a remarkable character of extremely high optical density on the X-ray films, and it is called halo. Joint paper from Mt.Fuji and China-Japan collaboration presented the intensities of the halo events (HE 3.4-9). The comparison with a Monte Carlo simulation including the halo development inside the chamber suggests more than 3 times lower proton abundance in 10^{16} -10^{17} eV range than that of 10^{12}-10^{13} eV within the framework of quasi-scaling model as shown in Fig.14. Here the geometrical size of the halo defined as an area with optical density greater than

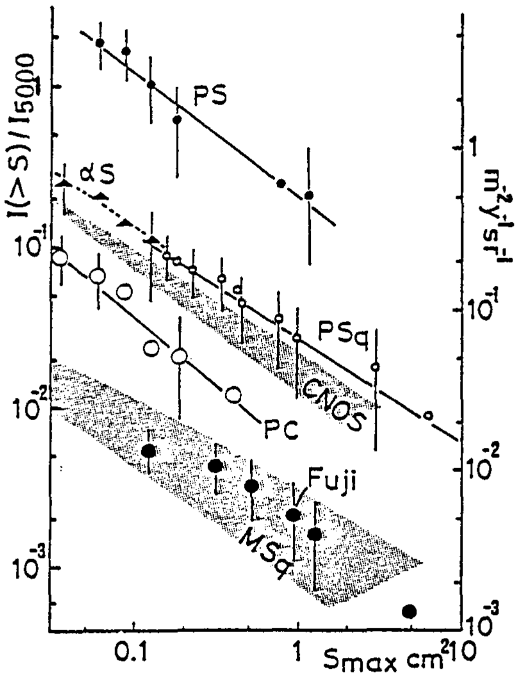
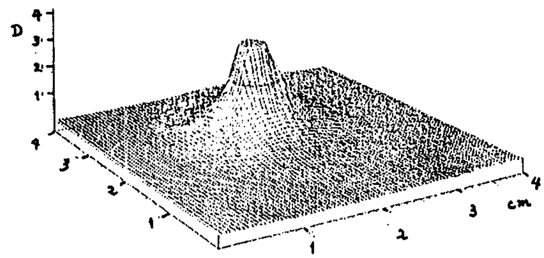


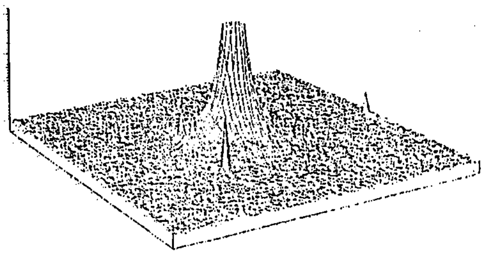
Fig.14

0.7 on N-type X-ray film is shown on horizontal axis. High multiplicity model ($n \propto E_0^{1/4}$) cannot reproduce the observed intensity of the halo events when the increase of the cross section and the primary chemical composition are adequately accounted for. Therefore, halo itself is not an exotic phenomenon but its low intensity is the largest problem. Since most of the halo events are induced by protons, such low intensity requires proton-poor primary chemical composition in 10^{16} -10^{17} eV range, say less than 10 %. Both results from Mt.Fuji and Mt.Kanbala experiment are consistent within statistical errors with the calculation based on those assumptions.

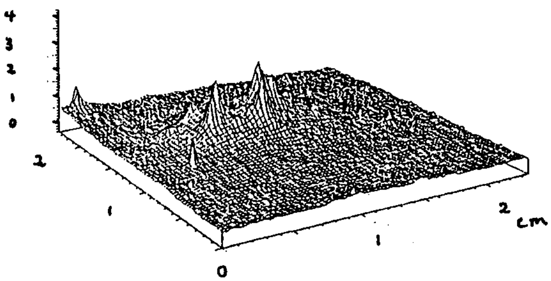
Some examples of optical density map are shown in Fig.15 for experimental data by Mt.Fuji collaboration and artificial ones by simulation (HE 3.4-9), though the structure of those events is not fully discussed yet.



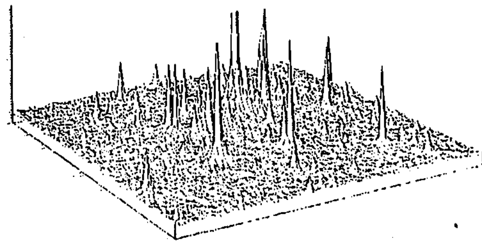
(a) Experimental:FH-89
E_{halo}=2300 TeV



(b) Simulation:Proton primary
E_{halo} =2300 TeV



(c) Experimental:FC-104
E_{halo}=3000 TeV



(d) Simulation:CNO primary
E_{halo}=2480 TeV

Fig.15 Optical density map of halo.

N.M.Amato, N.Arata and R.H.C.Maldonado (HE 3.4-5) presented an analysis of a halo event named P06 of the total visible energy 1300 TeV. According to their interpretation, central part of this event is formed by 'Giant-Mini-Cluster' with extremely small Pt of 30 MeV, whose characteristics are discussed by papers of Brazil-Japan collaboration (HE 3.5-4).

Another extremely exotic nature of the high energy interactions is reported by Pamir collaboration (HE 1.4-12). Some energetic events over 10^{15} eV show a coplanar emission of high energy photons as shown in Fig.16. The strong correlation among high energy photons were shown from the asymmetry analysis including the accompanied photons outside of the halo, though its interpretation is still open.

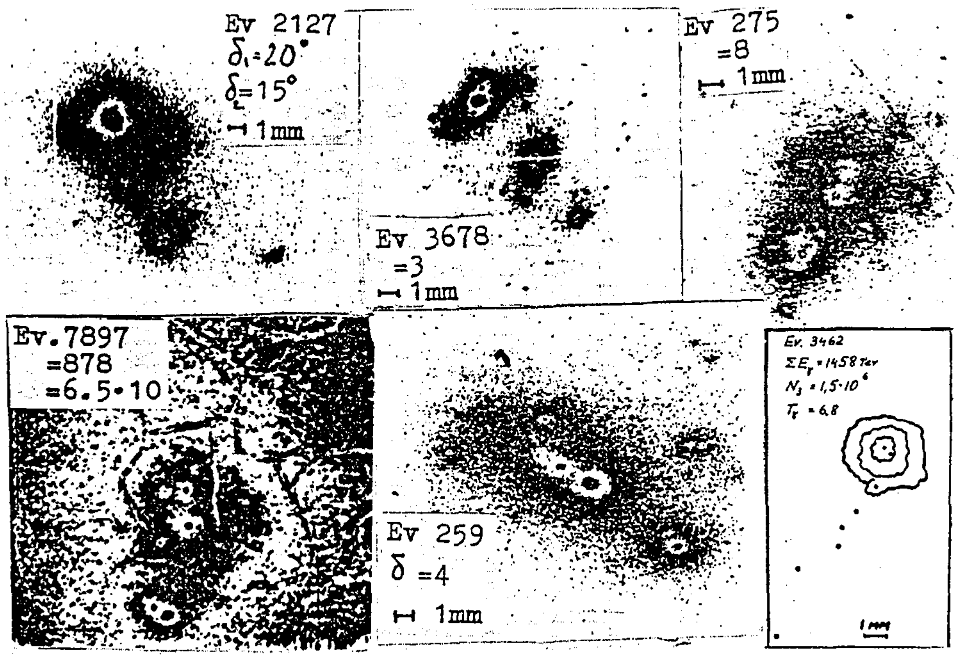


Fig.16 Coplanar events observed by Pamir experiments.

Summarizing the papers on halo phenomena, which correspond to the primary cosmic ray energy of 10^{16} -10^{17} eV, the intensity and energy flow properties are also explained by the same Monte Carlo calculations based on quasi-scaling model and heavy-enriched primary composition. In this energy range, the proton abundance was assumed as less than 10 % of the total primary intensity. If we assume more primary protons, then we need to introduce violation of scaling in fragmentation region stronger than one assumed in this calculation, though not as strong as CKP-type, because halo is created by very high energy electromagnetic particles, which are most probably produced in fragmentation region. It is reported by Pamir collaboration (HE 3.4-10, HE 3.4-11) that some of the halo events may be attributed to only few energetic photons. Sometimes only one photon produced high in the atmosphere is enough to construct observed characteristics of the halo spot. From those considerations, the fragmentation secondaries seem not to be disappearing in very high energy interactions.

The coplanar events detected by Pamir experiment seem to indicate an existence of strikingly unknown features of very high energy interactions.

6. Exotic phenomena

Since the observation of the event 'Centauro I'[17] by Brasil-Japan collaboration, extensive searches of peculiar events were made on gamma-hadron families and C-jets by the same authors. Though no Centauro-like events were reported, a scheme of the interpretations on those interaction mechanisms was discussed in this conference. The new mechanisms are named by those authors as 'Centauro' - pinaught-less particle production, 'Mini-Centauro' - hadron-rich events, 'Chiron' - Pt ≃ 2-3 GeV/c, 'Geminion' - binocular events, 'Mini-Cluster' - Pt ≃ 10-20 MeV/c and 'Giant-Mini-Cluster' - ensemble of mini-clusters.

A search was carried out by H.Kumano for the anomalous events among C-jets at total visible energy greater than 5 TeV (HE 3.2-5). Among 150 C-jets, the author assigns 9 events as anomalous ones because of non pinaught character and/or the large transverse momenta.

Another paper by Brasil-Japan collaboration also reported exotic interactions among C-jets and Pb-jets from the systematic analysis of Charaltaya CH-19 (HE 3.2-6). The decisive characteristics common to all these exotic interactions stated by authors are : (1) - unusually large Pt and (2) - no neutral pions produced in an interaction. The origin of cascades registered in the chamber were understood to be hadrons if the shower spot was visible only in depths greater than 6 c.u., or if their cascade curves were obviously not like electromagnetic ones, or if they were showing a clearly multi-core structure. Eight events with 2 showers and another eight with 3 showers are reported because of the invariant mass greater than 200 MeV/c^2 or the association of hadrons. The resemblance of these events to Mini-Centauro interactions is shown in the Pt and fractional energy distributions (Fig.17), which may be characterized by <Pt(gamma)> = 0.35 ± 0.05 GeV/c and initial

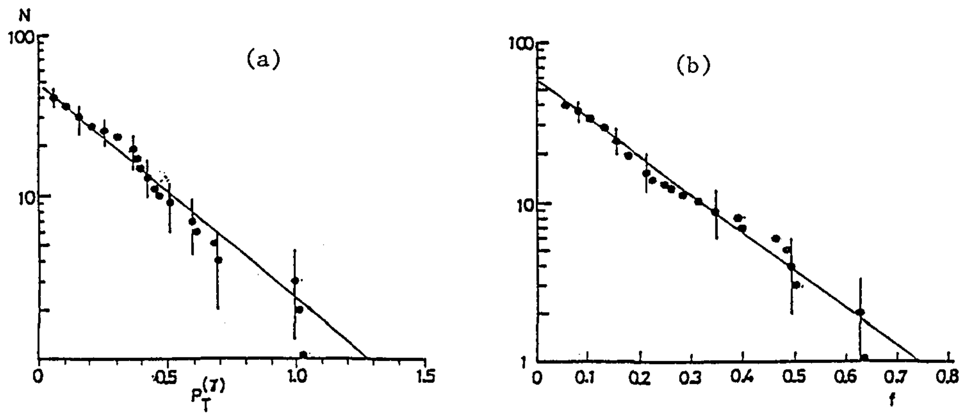


Fig.17 (a) Pt distribution and (b) fractional energy distribution for exotic C-jet events.

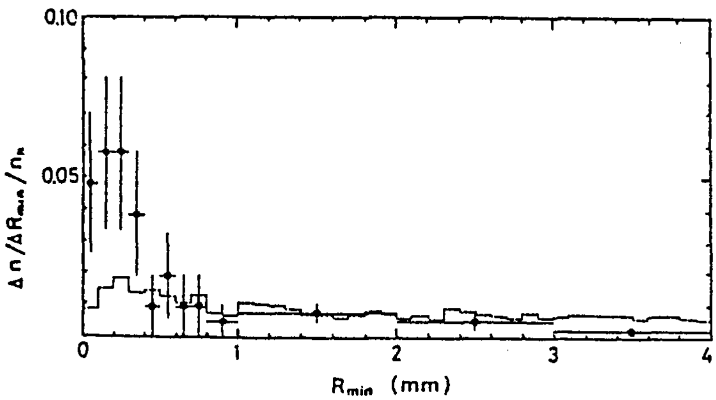


Fig.18

multiplicity $<m_0> = 18 \pm 3$. The parent interaction energies which give rise to these exotic events is estimated as 100 to 400 TeV.

M.Tamada showed the mini-cluster structure from the study of the correlations between hadrons and electromagnetic particles of the gamma-hadron families of Chacaltaya experiment (HE 3.3-6). There exist a number of hadrons which accompany electromagnetic showers very closely as shown in the distribution of relative distances between a hadron and its nearest neighbouring shower (Fig.18). Another feature is that the hadron carries a large portion of the cluster energy. They form a mini-cluster whose members carry transverse momentum about 10 times smaller than in normal production process.

Another paper by Brasil-Japan collaboration presented detailed characteristics of the mini-clusters (HE 3.5-3). The authors select the gamma-hadron families penetrating through both upper and lower chambers and having $<ER> > 180$ GeV m after the decascading with Kc=6 GeV m. Single-cored and mini-clustered high energy showers (>10 TeV), spreading from 0.1 to a few mm of radius, are investigated in detail. The multiplicity distribution of mini-cluster constituents is shown in Fig.19. The lateral structure of those families is interpreted as the result of Chiron interactions with $Pt \simeq 2$-3 GeV/c and mini-cluster formation with $Pt \simeq 10$-20 MeV/c by the secondary interactions.

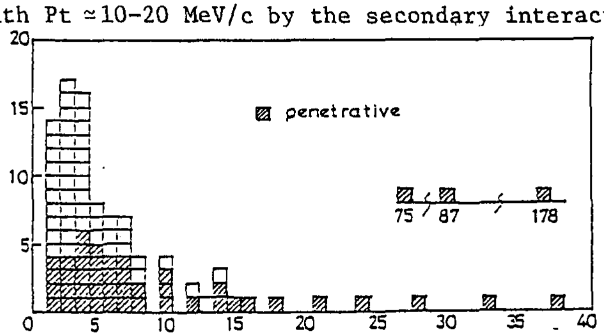


Fig. 19 Histogram of shower core number in a mini-cluster.

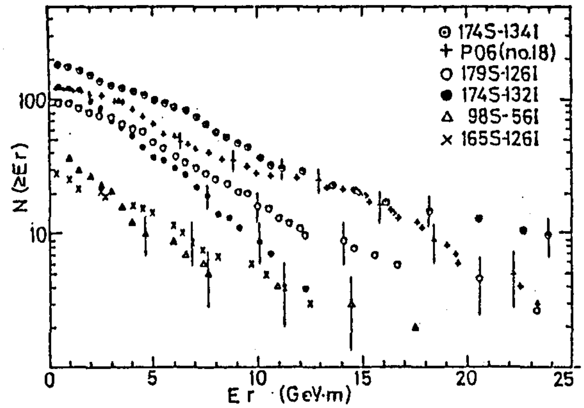


Fig.20

The mini-clusters with high multiplicity (m >30) are called 'Giant-Mini-Cluster' (HE 3. 5-4). They show small spread corresponding to extremely high rapidity density and strong penetrative power. The inner lateral distribution of giant mini-clusters shows high similarity of exponential type among different events as shown in Fig.20. Giant-mini-cluster is interpreted as an ensemble of mini-clusters and it is suggested as a possible cause of halo in large families.

The characteristics of hadron families are investigated on Charaltaya carbon chambers by H.Aoki (HE 3.3-4). The hadron multiplicity distribution is compared with current model calculations with primary protons in Fig.21. The excess of the hadron-rich events ($Nh > 9$) to proton-initiated artificial families is shown, though there is a possibility of explaining it with heavy primaries. In the correlation between Nh and <ERh>, the majority of experimental data are explained as fluctuations of ordinary interactions, but Centauro I and its candidates (Centauro II,III,IV) are not explained by this argument.

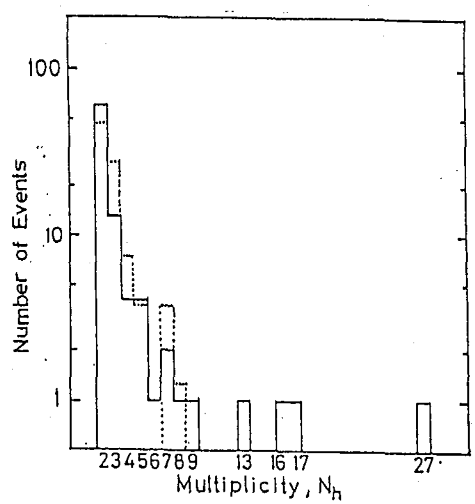


Fig.21

Summarizing the papers on exotic phenomena, Brazil-Japan collaboration concludes that 5-10 % of observed events cannot be attributed to ordinary interactions. Japan-USSR collaboration (HE 3.4-8, HE 3.5-2) also reported observing mini-clusters in Pamir carbon chambers.

The energy threshold for those exotic phenomena is estimated to be around 100 TeV, though searches by present accelerator data showed negative results. This situation is explained by the authors: either the threshold energy is a little higher than SPS-energy or there is a genetic relation between the exotic phenomena, namely, the secondaries from a Chiron interaction at very high energies maintain the exotic characters and produce mini-Centauro, Geminion and mini-clusters in successive interactions in the atmosphere. These exotic phenomena reported by Brazil-Japan collaboration are derived by focusing their attention on events of unusually large lateral spread or of hadron-rich nature. This is, however, fully related to the problem of the fluctuations in 5-10 % tail. Therefore a comparison with detailed Monte Carlo simulation is needed to exclude the possibility of explaining these events as just fluctuations in ordinary interaction process. As mensioned before, the large lateral spread of 7 % of gamma-hadron families can be attributed to the heavy primary nuclei. In the discussion of hadron-rich events or the mini-clusters containing hadrons, the reliability of hadron identification is the most essential point, because mini-clusters showing transverse momentum of 10-20 MeV/c can be interpreted as trivial electromagnetic cascades if they lack hadrons inside. Those procedures of hadron identification are also related to the problem of the fluctuations in the development of electromagnetic cascades.

7. New technics

Taira T. et al. (HE 3.1-13) presented a paper on a high sensitive screen type X-ray film (Fuji G8-RXO) and luminescence sheets (Fuji 'Imaging Plate'). Those films are irradiated to the electron beam to obtain the characteristic curves. They show quite high sensitivity compared to the currently used films like N type and other similar ones. The detection threshold energy for the cascade shower observation is also tested by baloon experiment and found to be around 200 GeV.

A new clustering procedure is proposed by Nanjo H. (HE 3.7-4) based on the idea of a variable cut off value for decascading instead of the constant ER in other methods. The new method is applied to simulated data and the validity of the procedure is examined on initial number of gamma rays, initial photon energy of a cascade and the sensitivity to the transverse momentum. The results seem to be encouraging.

8. Cascade calculations, propagations

There were 11 papers on cascade studies or cosmic ray propagations in the atmosphere. A.Wasilewski and E.Kryś (HE3.6-10,HE 3.6-11) made a detailed Monte Carlo simulation both in lead and air including every possible electromagnetic processes. They gave a new approximation formula for electron lateral distribution, which shows some deviations from NKG formula. This formula explains the discrepancies between experimental data and NKG formula, for instance the change of age parameter with the distance from the shower axis.

Ivanenko I.P. et al. (HE 3.5-12, HE 3.5-13) made calculations of electromagnetic cascades for higher moment characteristics, i.e., variations, asymmetry and excess.

Other papers in this field also show some useful results, however, due to the limited space, I would like to suggest to look at papers by A.Liland (HE 3.1-9), A.V.Plyasheshinikov (HE 3.5-9), Yu.P.Kratenko and S.A.Charishnikov (HE 3.5-10), R.M.Golynskaya et al. (HE 3.5-11), T.Yanagita (HE 3.6-7) and A.Tomaszewski and Z.Włodarczyk (HE 3.7-3).

9. Hybrid experiments

There are several stations where hybrid experiments are under operation. They are Tien-Shan station (K.V.Cherdyntseva et al. HE 3.2-7), Chikovani station (Yu.G.Verbetski et al. HE 3.2-8, HE 3.2-9), Mt.Chacaltaya station (Matano T. et al. HE 3.3-8, HE 3.3-9) and Mt.Norikura station (Shima M. et al. HE 3.3-10, HE 3.3-11).

Matano T. et al. (HE 3.3-8, HE 3.3-9) reported a detection of very high energy gamma-hadron family in an air shower core, whose age parameter is estimated to be 0.17. The association of such a young air shower to the high energy gamma-hadron family suggests that the primary particle of this event is a proton.

The installation reported by Shima M. et al. consists of EAS array, EC and burst detector below EC. EAS size spectrum is obtained in two trigger conditions. One is a usual air shower trigger and another is a burst trigger below EC. EAS size spectrum accompanied by gamma-family of total energy greater than 10 TeV is presented in Fig.22. The result agrees with the simulated data for proton poor primary composition of less than 15 % better than the proton-rich one of more than 30 %.

This kind of the experiment is a promising one because of the high sensitivity to the chemical composition of primary particles. Though the available data are limited at present, the possibility to extend the experiment is not limited compared with storatospheric experiment.

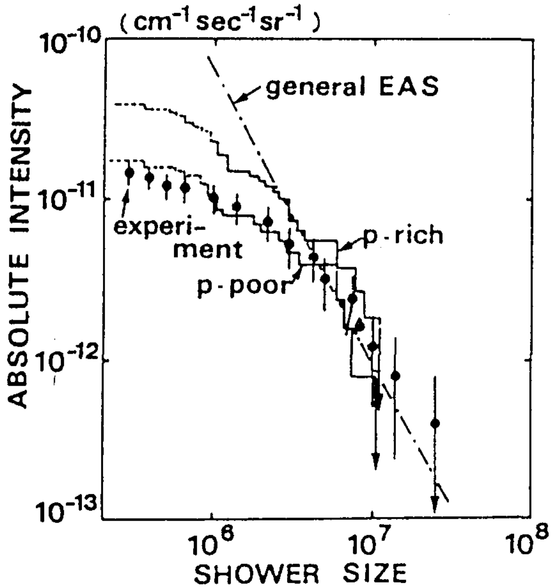


Fig.22

10. Conclusions and prospects for future

One can explain emulsion chamber data by so called quasi-scaling interaction models if primary proton spectum becomes steeper around 10^{14} eV. Already a lot of works have shown the mutual consistency among various features of the EC data. One can say, that at least no serious difficulty is known up to now in this framework.

One may argue, however, that the proton percentage at these energies is larger, and thus a more serious scaling violation in fragmentation region has to be assumed. There has been also a number of papers discussing about such possibilities[18]. In high multiplicity model, however, difficulties arise in reproducing the frequency of the binocular events and halo events, which are effectively produced in case of low multiplicity with high secondary energies. Therefore, the high multiplicity model can survive when the multiplicity distribution has a great fluctuation as discussed by J. Wdowczyk[19].

As to the exotic events, we need stronger evidence in order to confirm that they are really new phenomena. More simulations are needed to exclude the background events from fluctuations of ordinary interactions or heavy primary effects.

To get an increased sensitivity to the primary composition, an importance of hybrid experiments was discussed in this conference. Simulteneous informations from Emulsion Chamber and air shower array will bring us less ambiguous conclusions. Such experiments are being developed, for example, ANI experiment at Aragatz station, Mt.Chacaltaya, Mt.Norikura and others.

The continuation of the exposures of EC is also important to increase the statistics significantly for very high energy events like halo. The large scale EC experiments are also developing, for example, at Mt.Kanbala by China-Japan collaboration and Pamir plateau by Japan-USSR collaboration (HE 3.1-1). Fragmentation region at very high energies can be studied through those observations.

These situations are illustlated in following chart.

I

Fraction of primary protons

small → Very mild scaling violation in fragmentation region

Knee in proton spectrum:

$\sim 10^{14}$ eV

large → Scaling strongly violated in fragmentation region

Energy independent composition up to 10^{17} eV

II

Exotic Events

either → New phenomena

???

or → Fluctuations
Heavy primary effects

(Stronger evidence necessary)

III Importance of hybrid experiments : Increased sensitivity to composition

IV Large exposures :
- halo phenomena
- fragmentation region at very high energies
- structure reflects (maybe ?) the kind of primary particle

→ Significant increase in statistics is necessary to draw conclusions.

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