PARTICLE INTERACTIONS AT ENERGIES OVER 1000 TeV INFERRED FROM GAMMA-FAMILIES OBSERVED 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

Scaling, mean P_t, high P_t jets and others at energies over 1000 TeV are discussed on the basis of gamma-family data with $\Sigma E_\gamma > 100$ TeV, observed at Mt. Fuji (3750 m). These quantities are examined in connection with the primary composition.

1. Introduction.

At present, an observation of cosmic ray phenomena is a unique source to get a direct information about particle interactions at energies over 10^{15} eV. Among these, emulsion chamber experiments produce fruitful results for this purpose. Since 1970, the large-scale emulsion chamber experiments have been continued at Mt. Fuji (3750 m, 650 g/cm^2). Now, the total exposure of chambers reaches about 1000 m^2.y and about 200 family events with $\Sigma E > 100$ TeV have been observed. Also we have reliable data about particle interactions at energies up to 150 TeV and this energy will go higher at Felmilab in very near future. So, within one or two years, we may give a definite answer to the alternative of 1) scaling break in the fragmentation region and proton dominant primary or 2) scaling and heavy enriched primary, which have been repeatedly discussed for a long time.

In this report, we discuss general features of particle interactions expected from the Mt.Fuji experiment,comparing with the Monte Carlo results, and also describe some characters of super-families.

2. Problem of the Feynman scaling in the fragmentation region.

It is well confirmed that the absolute flux of gamma-ray families at mountain altitude is the most sensitive to the energy spectra of particles in the fragmentation region, inelastic cross sections and also primary composition, 1).

In Fig.1 we compare our data with the Monte Carlo results which are simulated on the basis of the conventional model of the interaction and primary. The symbols used for classifying the model are : P means the proton primary , M the mixed composition (heavy dominant), S the scaling, F the fire-ball model (normalized to SPS data at 150 TeV), Q the QCD-jet, I the increasing cross section as $E^{0.04}$ and T the transverse momentum increasing with energy as $E^{0.04}$. The bending energy (Eb in TeV) of primary proton is denoted in the blacket (spectral index changes from 1.7 to 2.0) and other nuclei also become steeper at Z*Eb. The absolute intensity of assumed total spectrum is normalized to the Grigorov's one at energies around 10^{15} eV. Details of the simulation will be found in the other paper, 2).

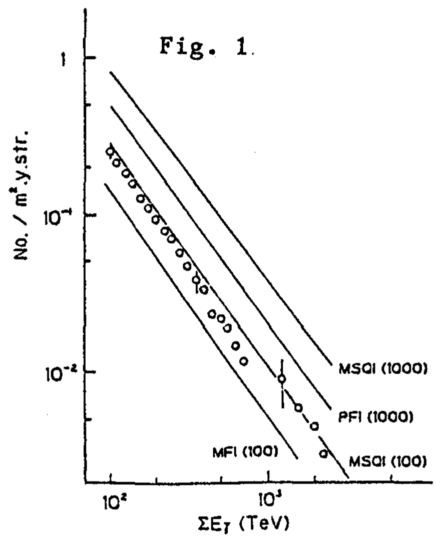


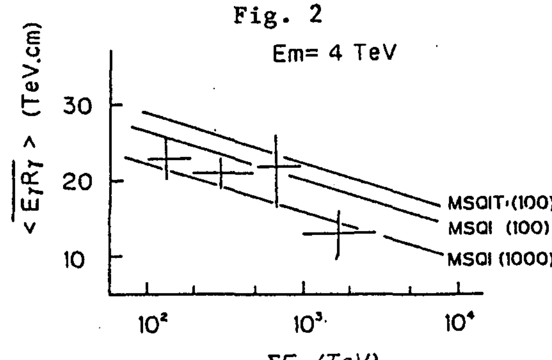
Fig. 1.

It can be understood that the scaling with heavy enriched primary is compatible with the experimental data. In this case, the proton component should become steeper at energies around 10^{14} eV. Of course, a strong scaling break and proton dominant primary (Eb~10^3 TeV) can also explain our data, but the fraction of protons to the total would not exceed 50 % at around 10^{15} eV (bending energy of proton spectrum).

3. Mean P_t at high energies.

The lateral spreads of constituent gamma-rays in the families give a measure of the mean P_t of secondaries at collisions. In Fig. 2 is shown the lateral spread, $\langle \overline{ER} \rangle$, averaged in the respective energy range, with the Monte Carlo results. In the acccelerator energy region, the mean P_t near

Fig. 2



the central region seems to increase with energy as $E^{0.04}$. If this increasing rate is hold up to higher energies, it takes about 450 MeV/c at 1000 TeV. However, as learned from this comparison, our data do not favour to increasing P_t (Here we discuss the P_t in the small P_t region. Note that the QCD jets are speciously taken into account in the simulation.). This result may suggest that the mean P_t depends very weakly on the primary energy, if any, or remains almost constant, since the family phenomena are very sensitive to the fragmentation region.

4. High P_t phenomena.

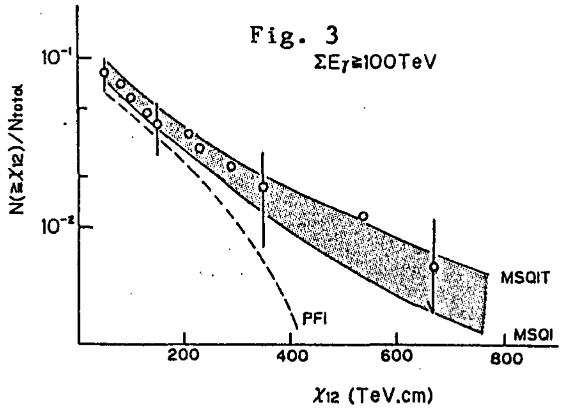


Fig. 3

In order to enhance the effect of high P_t, a clustering method is applied to the family phenomena. This method is already described in the paper, 3). Here we present the frequency of double-core events. In order to pick up such events, first we clusterize the gamma-families with ΣE_γ >100 TeV, then impose the following conditions : E1+E2 > 0.8 ΣE_γ and E1,E2> 10 TeV ; R12 > 5 max(r1,r2), where E1(E2) and r1(r2) is the energy and lateral spread of cluster 1(2) and R12 the distance between two clusters. In Fig.3 we show our data together with the Monte Carlo results. The frequency of double-core events with $\chi_{12}(=R12\sqrt{E1.E2})$ > 100 TeV.cm is about 7 %. This figure teaches us that such events are within the scope of expectation of the model based on the scaling with QCD-jets, and also a rapid energy dissipation model such as fire-ball is incompatible with the data.

Concerning to high P_t jets, we should note here that the peculiar event "TITAN", observed in 1977 and composed of 6 very high energy showers with E > 100 TeV, 4), is by no means produced by the conventinal interaction models according to our Monte Carlo simulation.

5. Super-families.

Here, we describe some features of super-families with E 1000 TeV. The primary energy responsible for generating such families would mostly exceed 10^{16} eV. A general feature of these super-families is expected to bring us a new clue for the study of particle interactions at energies 10^{16} - 10^{17} eV. A remarkable structure is that the majority of super-families is accompanied by a halo. In Fig. 4, we show the flux of gamma-families with ΣE_γ > 1000 TeV (E_m=4 TeV) and halo events at Mt.Fuji. Here, the energy of halos is estimated by using a relation of E=C*Z_0, where Z_0 is the total track length and C the conversion factor of 10 MeV/c.u.. As discussed in other paper, the flux of halo events can also be explained by the model mentioned above, 5).

At present, we have 6 halo events with energy exceeding 1000 TeV. The biggest event is the FC-31 with energy of about 9000 TeV. Two patterns are found about halo structure, i.e., single and axial-symmetric core or multi-cores. Examples of the event, FH-89 (2500 TeV) and FC-104(4000 TeV) are shown in Fig. 5 and 6. Three among 6 events have a single-core structure. In

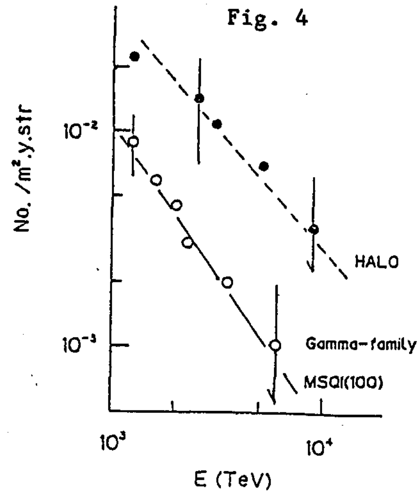


Fig. 4

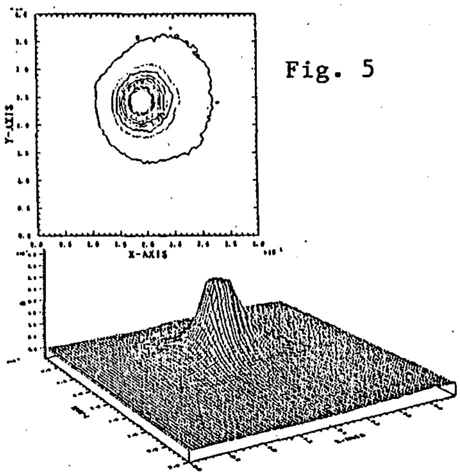


Fig. 5

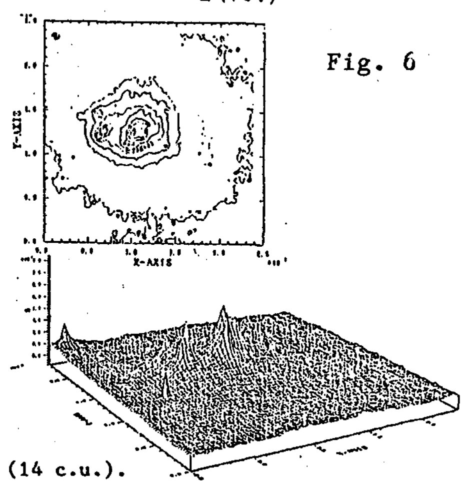


Fig. 6

Fig. 5 : FH-89 (36 c.u.), Fig. 6 : FC-104 (14 c.u.). Density map of X-ray film measured by photometer. Area : 24x24 mm^2, Slit size : 300 microns, Z-axis : Density from 0-3.0.

particular, no high energy showers are found in the outskirts of the halo of the event FH-89 , strikingly different from other two, as noticed from Fig. 5. According to the Monte Carlo simulation, such type of events are possibly produced by protons deep in the atmosphere and the structure of the event FH-89 may suggest a look of very high multiplicity. We need more events to reach some conclusive results.

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