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A Superhigh Energy Gamma-Ray Family Event in the Form of Two Concentric Rings

Ren Jingru, Kuang Haohuai, Huo Anxiang, Lu Suiling, Su Shi and Wang Yunxin[1]; Wang Chengrui, Zhang Naijian, Cao Peiyuan, Li Jinyu and Zou Baotang[2]; Wang Shizhi[3]; Li Guangju and Bai Guangzhi[4]; Mu Jun and Zhou Wende[5]

([1]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing)
([2]Department of High Energy Physics, Shandong University, Jinan)
([3]Department of Physics, Zhengzhou University)
([4]Chongqing Architecture College)
([5]Department of Physics, Yunnan University, Kunming)

A superhigh energy gamma-ray family event with the showers distributed in the form of two concentric rings has been found in the Mt. Kanbala emulsion chamber experiment. The radii of the two rings are 4 mm and 10 mm respectively. This event exhibits some features clearly deviated from those of ordinary big family events. In this paper, some characteristic features of the rings are analyzed and a short discussion is made.

1. INTRODUCTION

The study of cosmic ray superhigh energy interactions usually relies on the accumulation of a sufficient number of events, the acquisition of various statistical distributions and the comparison of the observations with the results of Monte Carlo simulation based on the assumption of various models so as to search for some clues to the interaction mechanism and the primary cosmic ray composition. However, due to the very low flux of superhigh energy ($E_0 > 10^{15}$ eV) cosmic ray particles, it is very difficult to obtain a fairly large number (say, a few hundreds) of events with $\Sigma E_\gamma > 1000$ TeV even with a large-area detector under a long-time operation. One of the roles

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TABLE 1
Mean Quantities of Event K4108

E_{min}	$\langle R\rangle = \sum R_i/N$	$\sum E_iR_i/\sum E_i$	$\langle ER\rangle = \sum E_iR_i/N$	$\langle E\rangle = \sum E_i/N$
3TeV	23.9mm	18.2mm	20.2TeV · cm	11.1TeV

which should be played by the experiments of cosmic ray high energy physics is to present some useful ideas for making a deep and careful study in experiments and in theories through the observation of rare exotic events, thus giving people some enlightenment. There are a lot of work in emulsion chamber experiments stressing on the analysis of relatively rare exotic events to look for the possibilities of obtaining some new results. But it must be admitted that not all the exotic events might lead to novel results, sometimes this is due to the experimental limitations and uncertainties, or only statistical fluctuations. In the last few years, some events with ring-like distribution of shower spots have been observed in balloon emulsion chamber experiments [1] and the so-called "spike" phenomena found in the collider experiments [2]. These events were interpreted by some authors as a manifestation of the phase transition produced in superhigh energy nuclear-nuclear interactions. Recently we have found an event, named K4108, in the Mt. Kanbala emulsion chamber experiments in a higher energy region ($\sim 10^{16}$—10^{17} eV), in which the shower spots are distributed in the form of two concentric circular rings. Nearly all the high energy shower spots constituting the event are concentrated on two rings with radii of 4 mm and 10 mm respectively. There is almost no high energy shower spot existing in the central region of the event. Some characteristic features of this ring-like event are introduced in this paper.

2. EXPERIMENT

300 tons of Fe emulsion chambers (thickness 29 c.u., area 58.4 m^2) and 83 tons of Pb emulsion chambers (thickness 14 c.u., area 83 m^2) were exposed at the top of Mt. Kanbala (5,500 m above sea level, atmospheric depth 520 g/cm^2) in the period from May 1984 to May 1985. The photosensitive materials used were Sakura N type and Fuji 100 type X-ray films and ET7C nuclear emulsion plates made in Japan and Tianjin-III type high Ag content X-ray films made in China. The energy calibrations were made with the ET7C emulsion plates.

A gamma-ray family event, K4108, was found in a block of Pb chamber in the central part of a Tianjin-III high Ag content X-ray film (with size of 11" × 14"). It consists of near 900 showers with energies above 1 TeV. If the threshold energy is taken to be 3 TeV, then the total visible energy of the event is ΣE_γ = 7600 TeV. The tangent of the zenith angle of the event is m = 0.44. Nearly all the high energy showers lie on two concentric circular rings of radii 4 mm and 10 mm. Only a few shower spots are situated in the center of the rings, and no high energy showers there. The mean quantities describing the basic features of the event are given in Table 1, where E_{min} is the threshold energy of the selected shower spots, and $\Sigma E_iR_i/\Sigma E_i$ is the energy-weighted mean radius. The mean quantities of lateral spreads $<R>$ and $<ER>$ are consistent with those in ordinary family events of total visible energy $\Sigma E_\gamma > 1000$ TeV, and basically in accord with the prediction of the model MSQI within the range of statistical fluctuation [3] (The mean lateral spreads of general big family events with $\Sigma E_\gamma \gtrsim 1000$ TeV given by experiments and the model MSQI are as follows: $<R> \approx 2$ cm, $<ER> \approx 20$ TeV·cm).

The energy spectrum of the showers in the family is given in Fig.1, which is also close to that of ordinary gamma-ray families of $\Sigma E_\gamma > 1000$ TeV [4]. Therefore, the mean quantities and integral

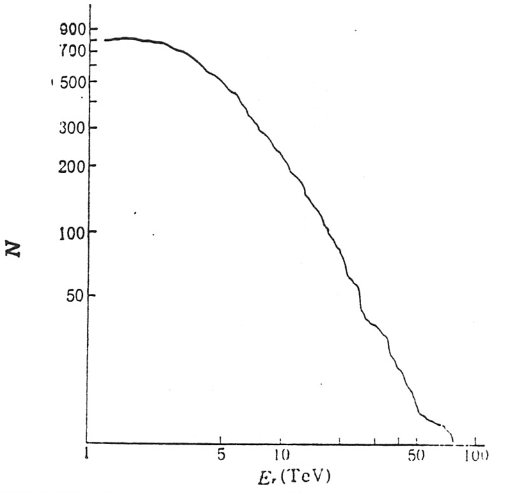

FIGURE 1 The integral energy spectrum of showers in K4108.

energy spectrum, which are usually used for roughly describing the general features of gamma-ray family, cannot reveal the special features of the ring-like family event.

3. THE CHARACTERISTIC PROPERTIES OF RING-LIKE EVENT

Generally speaking, showers with energies higher than 10 TeV in a family are more informative for the primary interactions than those with lower energies. The target map of showers with visible energies higher than 10 TeV in the event K4108 is shown in Fig. 2, from which the ring-like distribution of showers is presented. Obviously, the azimuthal angle distribution of the shower spots is not quite homogeneous due to the statistical fluctuation. Let R_i be the distance of i-th shower spot to the energy-weighted center "0" of the event, and the coordinates of point "0" are defined as follows: $\bar{x} = \frac{\sum E_i x_i}{\sum E_i}$; $\bar{y} = \frac{\sum E_i y_i}{\sum E_i}$. The point "0" is considered as close to the intersection point of the incident particle producing main nuclear interaction with the observation plane. In

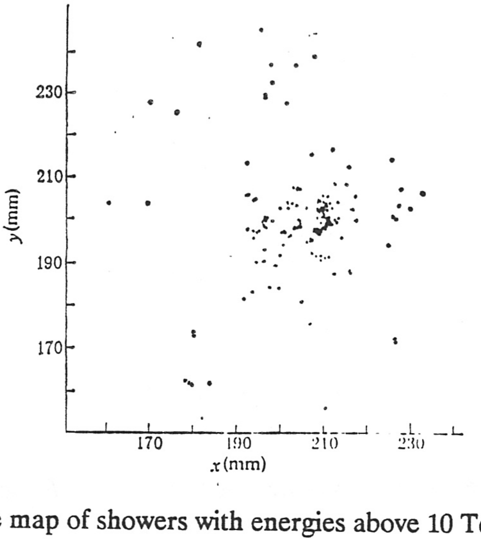

FIGURE 2 The map of showers with energies above 10 TeV in event K4108.

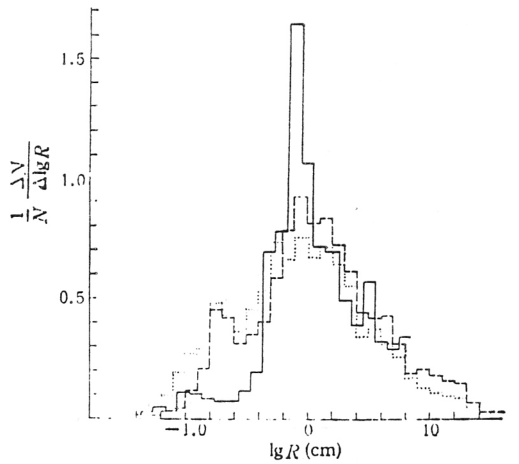

FIGURE 3 The lg R distribution of event K4108.

order to describe the characteristic features of the ring-like event quantitatively, we can plot the lg R distribution. The lg R distribution of the event K4108 is shown in Fig. 3, where the dotted and dash lines represent the simulation results for the family events of visible energy larger than 3000 TeV (average results of 30 events). In these simulations, the interaction model is taken to be Feynman scaling plus jet production, with the inelastic cross-section increasing proportional to $E^{0.06}$ and mean transverse momentum $<p_t>$ equal to 330 MeV/c (SQI); the observation level is on the top of Mt. Kanbala (520 g/cm^2; the showers with starting point depths $\Delta t > 6$ c.u. are defined as hadrons; HD means heavy-nuclei dominant primary composition, and the fraction of Fe nuclei is about 40% in the primary particles; PD means proton dominant, and the fraction of proton in PD is about 20% larger than that in HD (for the primary energy $E_0 \approx 10^{15}$—10^{17} eV). It can be seen from Fig.3 that the maximum value of experimental distribution is almost twice higher than those of the simulation calculations in the region of lg $R \approx 0$. In order to see the properties of the rings more clearly, we change the origin of coordinates from the energy-weighted center selected above to the geometrical center of rigs in target map, and use the new origin for plotting the R_1 vs. E_γ

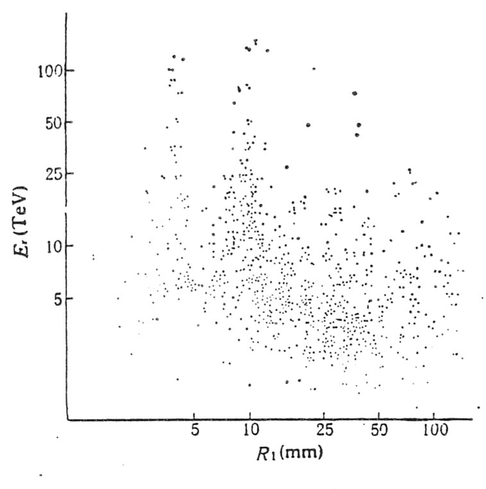

FIGURE 4 The correlation of the shower energies E_γ and the distances R_1 in the event K4108.

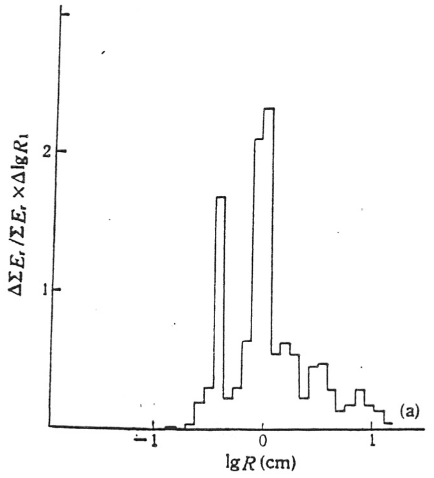

FIGURE 5a The energy flow distribution of event K4108, taking the geometrical center as the origin.

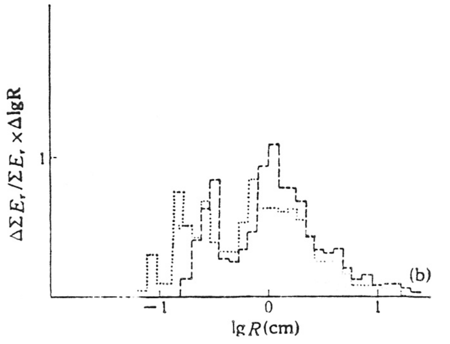

FIGURE 5b The energy flow distribution of the events with total visible energy $\Sigma E_\gamma > 3000$ TeV, taking the energy-weighted center as the origin.

distribution shown in Fig.4. It can be seen from Fig.4 that two bundles of high energy showers are concentrated on the rings of radii $R_1 \approx 4$ mm and 10 mm respectively, only a few high energy shower spots are situated in other place, and almost no shower spot with $E_\gamma > 10$ TeV is found in the central region with $R_1 < 4$ mm. In order to see the fact mentioned above clearly, the energy flow distribution is given in Fig.5a. It shows two prominent peaks located at the positions of $\lg R_1 \approx -0.3$ and $\lg R_1 \approx 0$. Comparing this with the results of simulations, which are similar to those shown in Fig.3, it can be seen that the two peaks are twice higher than those of the simulation calculations (Fig.5b).

4. DISCUSSION

Summarizing the above-mentioned experimental results, it can be deduced that the event K4108 is a relatively exotic gamma-ray family event. The production height is higher, and it is difficult to be determined by using a simple geometrical method. The showers of higher energies in the family are distributed on two rings. The visible energy in the inner ring is $\Sigma E_\gamma \approx 1340$ TeV, and in the outer ring $\Sigma E_\gamma \approx 2440$ TeV. The total visible energy in both rings is about one half of those of the whole family. Since the total number of shower spots is $N\gamma = 900$ and the majority of the shower spots lie on the rings, it seems improbable that these two rings are the consequences of the statistical fluctuations. The characteristic features of this event are clearly deviated from those of the general simulations and the ordinary big family events.

No explicit line can be drawn between the ring-like events and the multi-core events. For example, of the five main cores in the event K0E19 [5], four are distributed on a circular ring shown in Fig. 6, while the other one is situated in the center of the ring. The remarkable feature in the picture of the ring-like events distinguishing from the general big family events is that the majority of the high energy shower spots are deviated from the center of event and concentrated on a circular ring. Therefore an empty hole is formed around the central region. It indicates that the secondary particles produced in high energy nuclear interactions are emitted from a small angle in a concentrated form. Assuming ψ as the emission angle, then most of the particles are emitted from

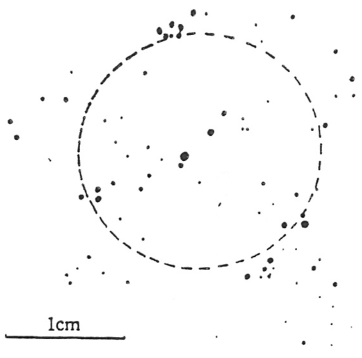

FIGURE 6 The target map in the core region of the event K0E19.

the region between two circular cone surfaces defined by the vertex angles ψ and $\psi + \Delta\psi$. After passing through the atmosphere, the particles arrive at the emulsion chamber, and the ring is formed by the transverse section of the circular cone. The inner one of the two concentric rings in K4108 is very clear, and the width of which is narrow. The appearance of the ring shape depends considerably on the selection of the origin of coordinate system. Therefore, it is very important as to which coordinate system is chosen for describing a super family event. But, either in the energy center coordinate system or in the geometrical center system, a peak of the main ring will appear clearly in the lg R distribution of showers in the event. There is a possible explanation for the ring-like event. It is considered as an experimental manifestation of some new form of matter produced in superhigh energy nuclear interactions, a manifestation of the quark gluon plasma [2, 7], or as the Cerenkov gluon radiation [1]. Perhaps even more correct explanations exist, especially for the event of two concentric rings. It is expected that more exotic events will be accumulated in experiments and more information given in much higher energy region.

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