ICRR

ICRR-Report-381-97-4

**Contribution to IX International Symposium
on Very High Energy Cosmic Ray Interactions
(18-24 Aug. 1996, Karlsruhe)**

ed. by A. Ohsawa

(January, 1997)

5W9717

Chacaltaya and Pamir Collaborations

**INSTITUTE FOR COSMIC RAY RESEARCH
UNIVERSITY OF TOKYO**

3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan

Study of primary cosmic ray composition from gamma ray families in air shower cores

K. Honda^a, N. Kawasumi^a, I. Tsushima^a, K. Hashimoto^a, T. Nishida^b, T. Matano^b, N. Inoue^c, A. Ohsawa^d, M. Tamada^e, N. Ohmori^f, N. Martinic^g, R. Ticona^g, N. Gironda^g, F. Osco^g and C. Aguirre^g

^aFaculty of Education, Yamanashi University, Kofu, Yamanashi, 400 Japan

^bDepartment of Applied Physics and Chemistry, Fukui University of Technology, Fukui, 910 Japan

^cFaculty of Science, Saitama University, Urawa, Saitama, 388 Japan

^dInstitute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo, 188 Japan

^eFaculty of Science and Technology, Kinki University, Higasi-Osaka, Osaka, 577 Japan

^fFaculty of Science, Kochi University, Kochi, 780 Japan

^gInstituto de Investigaciones Fisicas, Universidad Mayor de San Andres, La Paz, Bolivia

We have observed high energy gamma families and associated air showers simultaneously at Mt. Chacaltaya. Monte Carlo simulations were calculated for the present experimental setup. From comparisons with both results, mechanism of gamma family production, change of interaction model, study of the chemical composition are discussed.

1. Introduction

Bundles of high energy ($E_\gamma > 1$ TeV) γ rays, electrons and hadronic γ rays have been observed with emulsion chambers at mountain altitude. The characteristics of nuclear interactions and the chemical composition of primary cosmic rays have been discussed.

In the recent experiments, we observed γ families by emulsion chambers installed in the center of SYS (Saitama, Yamanashi and San Andres University) air shower array and also air showers simultaneously[1]. In large air shower size region γ families are observed always in air shower cores. Such accompanied air showers provide important informations on behavior of γ families.

Since the air shower size is converted to energy of primary cosmic ray of air shower with the simple relation, we can study the relation of γ families and the primary energy of

associated air showers. It is impossible in emulsion chamber experiments without air shower informations to know the primary energy dependence of the number of γ family and also the energy spectra of γ rays in the γ families.

In order to understand experimental results in detail, the Monte Carlo simulation is important. So we calculated simulation for the present experimental setup.

In this paper, we shall discuss the production of γ family, its dependence on the chemical component of primary cosmic ray.

2. Experiments and Simulation

We have observed air showers and γ families with the SYS air shower array and emulsion chambers at Mt. Chacaltaya in collaboration with Japan and Bolivia. Gamma families are linked with particular air showers

as reported in other paper in this symposium[2]. Thus, we have informations on γ families and also associated air showers.

On the other hand, we calculated Monte Carlo simulations for the present experimental setup at Mt. Chacaltaya level[3]. We use UA5 simulation algorithm for the nuclear interaction model. This is the phenomenological simulation logic and reproduces the nature of multiple production of particles at $\sqrt{s} = 53, 200, 546$ and 900 GeV at the CERN SPS PP collider. Air showers are initiated in many cases by nucleus - air nucleus collisions. For such interactions, we assume the wounded - nucleon model. The wounded nucleon number is taken from the formula by Shibata et al.[4], which reproduces experimental data more satisfactorily than from the Glauber model.

For the simulations, the chemical composition of primary cosmic ray are assumed, since we have not yet real informations on it in the air shower energy regions. One is "normal" composition, which was estimated by Nikolsky. At the primary energy, 10^{15} eV, the component of proton is 42% and Fe is 13%. Other one is "heavy" dominant one. At the same energy region, proton content is 18% and the fraction of Fe is 39%. At energy 10^{16} eV, Fe increase to 47%. These "heavy" was introduced by China - Japan collaboration to explain their emulsion chamber experiment under assumption that the interaction model does not change drastically.

3. Results and Discussions

3.1 Production of gamma families

We determined integral energy spectra of γ rays in families, whose total energy ΣE_γ is in a given range of ΣE_γ , for different accompanied air shower size regions. For an example, we can determine these values as follows:

The range of ΣE_γ is $46.4 \sim 100$ TeV and the accompanied air shower sizes divided into 3

groups, $10^5 \sim 10^6$, $10^6 \sim 10^7$ and $10^7 \sim 10^8$.

Experimental results show that the integral energy spectra of γ ray in families in the same range of ΣE_γ coincide well each other, independent of the associated air shower size. Simulations show also similar results in the number of γ rays and the slope of the spectra.

From these results in experiments and simulations we can conclude that in most case, γ families are produced near observation level through interaction of high energy hadrons in air shower cores, which do not initiate nuclear cascade until the level. The interaction model of simulations reproduce the interactions of the parent hadron to γ families

Moreover, the conclusion from such results means also that γ family are not produced directly in the first interaction of air shower production.

3.2 Change of feature of nuclear interaction

It is shown in the above discussions that the interaction model can reproduce γ families production well. However, there are discrepancies between experiments and simulations.

One is on the intensities of γ families. Simulations produce higher intensity than experimental results. Second one is on the mean values of the total energy of γ families $\langle \Sigma E_\gamma \rangle$ for fixed accompanied air shower size. Simulations give higher mean values than experiments. These high values can not be reduced even with "heavy" chemical composition.

We can conclude that in such high energy region ($\geq 10^{16}$ eV) features of nuclear interaction change.

3.3 Production of parent particle for γ family

We determine from simulations the relation between the number of γ family and the size of associated air showers for proton primary and

also Fe primary. Results are shown in Fig. 1. In lower size regions, number of events are large difference between proton initiated air showers and Fe ones. Gamma families are found in proton initiated air showers even in lower region, but no γ family in Fe initiated air showers. However in higher size regions, there is no difference between both. Moreover, the distributions of the total energy of families are similar for proton and Fe.

These results also support that γ families are produced through interactions of the parent particles near the observation level. Moreover, these results support that we can compare simulations and experiments on γ family production to check the model of interactions in such higher energy region without the effect of inaccuracy of informations of chemical composition.

3.4 Study of the chemical composition

Fig. 2. shows the same relation for “normal” component and “heavy” component. In this case, the total energy of γ families is above 100 TeV. We can determine the ratio of the number of γ families in associated air showers with size above 6.8×10^6 to the total number of families. This ratio is 13.3% for “normal” component and 29.1% for “heavy” component.

When we have the accurate model of interaction, such a ratio can be determined from the simulation and be compared with experimental results to determine which of “normal” component and “heavy” is true.

Reference

- 1). N. Kawasumi et al., Phys. Rev. D 53, 3534(1996).
- 2) N. Kawasumi et al., present symposium
- 3). M. Tamada, J. Phys. G 20,487(1994).
- 4) T. Shibata et al., Phys. Rev. D 36, 783(1978)

Fig. 1. The relation between the number of γ family ($\Sigma E_\gamma \geq 10$ TeV) and the size of associated air showers for proton primary and Fe primary.

Fig. 2. The relation between the number of γ family ($\Sigma E_\gamma \geq 100$ TeV) and the size of associated air showers for “normal” and “heavy” component.