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Comparison of experimental and calculated data on gamma families with “halo”

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Abstract

The characteristics are presented of simulated haloes, created by the cores of the EAS which were initiated by different kinds of primary particles. The results show that the probability of creating a halo by proton initiated showers is high with respect to that of iron induced showers. A primary proton rather than heavier nuclei can produce the halo of big area as registered in experiments.

1 Introduction:

An emulsion calorimeter consists of a “sandwich” of lead, X-ray films and carbon layers. The calorimeter of the Pamir Experiment is exposed at 4370 m asl. The details of its chamber are described in (Baiburina S.G et. al. 1984). In the emulsion of the X-ray calorimeter exposed at mountain altitudes the particles from the cores of EAS are registered. In the upper part of the calorimeter the gammas and electrons/positrons from the EAS begin to create a cascade in the lead. The X-ray films, in which passing particles can be registered, are located under 4, 5 and 6 cm of lead. In the Pamir Experiment a bunch of particles, initiated by a primary nucleus (or photon), has similar zenith and azimuth angles and is called a γ-family. Separate cascades initiated by γ and electrons of energy greater than 2 TeV can be observed in the film with a naked eye as small dark dots of a diameter of several microns.

A γ-family is defined as a set of minimum 3 separate cascades with similar zenith and azimuth angles and located within a circle of 15 cm radius in the X-ray film. It is supposed that these cascades are originated by the same primary particle. For a primary proton with energy above 10^{16} eV a bunch of high energy particles is observed in the EAS core. Their mutual distances are so small that their tracks in X-ray film cannot be separated. In such a case a dot of a several sq. mm area and high optical density is often created and registered in the emulsion. Such a large area dot is called an optical “halo” (Borisov A.S. et al. 1997). The following phenomenological quantitative criterion of "halo" existence is accepted: the area S bounded by the isodensity line with optical density of darkness D = 0.5 is greater than or equal to 4 sq.mm (for multi-core "halo", the sum S_i of separate dots, each of area $S_i > 1$sq. mm., is not less than 4 sq.mm).

This paper describes characteristics of the simulated halos created by the cores of the EAS which were initiated by primary particles of different kinds.

2 Calculations:

The CORSIKA program (Heck D. et al.. 1998) was used to simulate development of the cores of extensive air showers in the air. The QGSJET model of nuclear interaction was taken into calculations. The cross sections for nuclear interactions were adopted in agreement with the model.

Primary particles which entered the atmosphere were sampled with the spectrum $\approx E^{-\gamma}$; the exponent of the integral spectrum is $\gamma = -1.7$ in the range 5.10^{15} – 10^{18} eV. Zenith angles varied from 0 to 40^{o}. In our

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calculations hadrons were traced down to the energy 20 GeV and the same threshold was applied to gammas and electrons/positrons.

To get a picture of optical halo in the X-ray film the passage of particles through the thickness of the X-ray chamber was simulated and the so called 'isodense' method described in (A.M. Dunayevski, M. Pluta, 1990) was used. In this paper it was assumed that only a gamma-electron component of the EAS core creates halo phenomena in the gamma block of Pamir calorimeter. This approximation is commonly used by the Pamir group and let us calculate haloes in the upper, consisting of lead, part of the calorimeter.

3 Results:

In the calculations, it is important to know what are the energies of those particles above the chamber, which can give contribution to the halo area. The dependence of the optical halo area on the threshold energy of gammas and electrons above the chamber is presented in Table 1.

Table 1 Estimation of the halo area as a function of the accepted energy threshold of gamma and electrons above the chamber.

energy threshold →	20 GeV	100 GeV	200 GeV
estimation of the halo area (the area of the halo estimated by gamma and electrons of energy, above the chamber, greater than 20 GeV is assumed as 100%)	100 %	97 %	81 %

It can be seen that particles of energy (above the chamber) between 100 and 200 GeV play an important role in contribution to the area of the halo. It may be concluded from the data in the Table 1 that if the accuracy of the estimation of the halo area is to be less than 5%, the energy of the particles should be not greater than 100 GeV. However, the time needed for the calculations increases very rapidly if the particles with energies less then 100 GeV are taken into account. The reasonable energy threshold of the particles above the chamber was taken as 100 GeV and was used for the calculations presented in this paper; the resulting underestimation of the halo area was about 4-5 %.

In Table 2 the ratio of the number of created haloes per 1000 proton initiated EAS is shown as a function of primary particle energy.

Table 2 The ratio of created haloes *per* 1000 proton initiated EAS in different intervals of primary particle energy.

energy of primary particle, PeV	5 - 10	10 -50	50-100	100 - 1000
the number of created haloes *per* 1000 proton initiated EAS (errors are of order 5-10 %)	7	165	180	340

It can be seen that the lowest energy for the primary proton to be able to create a halo is of order of a few PeV. For instance, the probability for the proton with energy from the interval 50 – 100 PeV to create a halo is 0.18. Iron initiated EAS do not create haloes in energy range below 100 PeV or the probability of creating a halo is very small. Iron nuclei with energy above 100 PeV begin to create a halo; in such a case the number of created haloes per 1000 iron initiated EAS is 98 and the area of the halo is not greater than 450 sq. mm.

The correlation between the area of a halo and the primary energy of the protons which are responsible for the halo creation is shown in Fig. 1. It can be seen that the protons of energy about 10^{16} eV begin to create a halo. The area of the halo produced by protons of energy below 8.10^{16} eV is not greater than

250 mm^2. It should be remembered that in X-ray film of emulsion chamber experiments the registered halos were of the area of a few hundreds sq.mm. The first famous event called "Andromeda" was found by Chacaltaya group and has the area above 1000 mm^2. (Fujimoto Y., 1993, RJKEN). In the Pamir Experiment there is an event "Fianit" which has 1017 sq.mm. also. The "Tadjikistan" event has about 1600 sq.mm. Such big areas of haloes can be created by proton initiated showers with energies greater than 10^{17} eV. A halo with the area of a few sq. mm was created in our calculations by an iron nucleus of energy above 10^{17} eV.

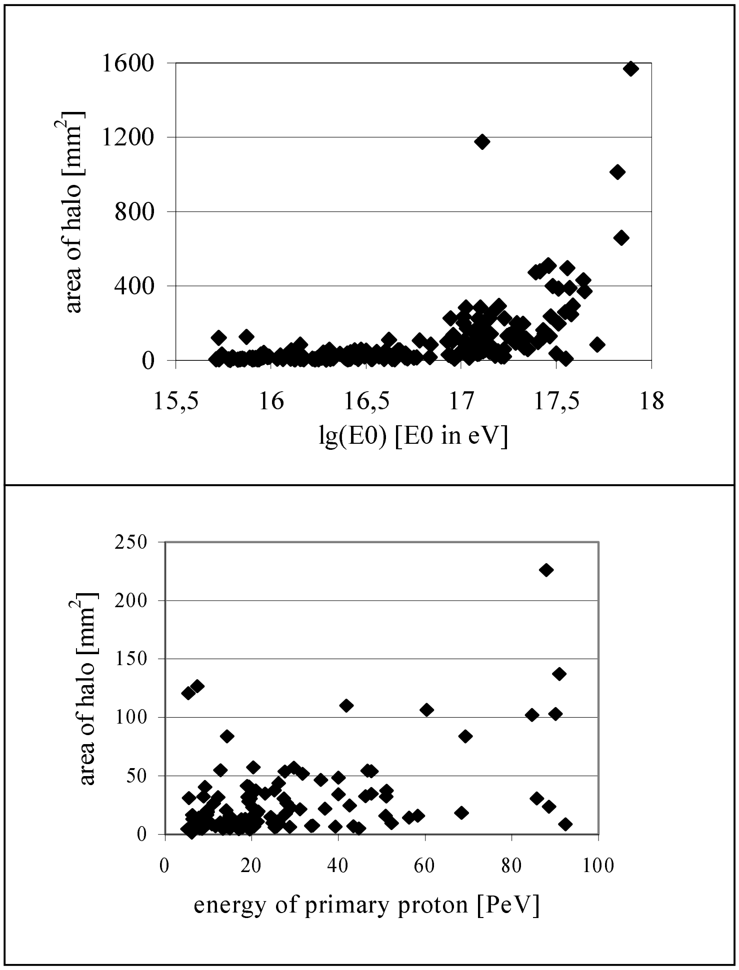

Fig 1 The correlation between the area of a halo and the primary energy of protons which are responsible for halo creation.

4 Conclusions:

The characteristics of the simulated haloes, created by the cores of the EAS which were initiated by different kinds of primary particles are presented in the paper.

The results show that the probability of halo creation by proton initiated showers is high comparing to iron induced showers. Primary proton rather than very heavy nuclei initiated EAS can produce the haloes, the large areas of which were registered in the experiments.

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