Two Anomalous Halo Events Obtained During the Hadron-44 Experiment on Tien-Shan Cosmic Ray Station

O.A. NOVOLODSKAYA, T.KH. SADYKOV, N.N. ZASTROZHNova, M.K. ZHUNUSBEKOV
Institute for Physics and Technology, Almaty, Kazakhstan
contact. sadykov@sci.kz

Abstract: During the “Hadron-44” experiment on Tien-Shan cosmic ray station, two anomalous halo events were obtained. These events are characterized by two peaks in calorimeter layers: at 500 g/cm² and at 1000 g/cm². Monte Carlo simulation (Corsika and Geant4 packages were used) showed that the obtained experimental data can’t be explained by simulation perfectly. In xrec-part of an installation simulation predict a higher primary energy than experimental methods gave. In calorimeter part the second peak can be hardly explained by high-energy muon interactions with a matter of calorimeter. Simulation gives a probability about 0.5%.

Keywords: EAS, halo, nuclear emulsion, ionization calorimeter, muons.

1 Introduction

In the beginning of 60s of the XX century in Tien-Shan mountains a High mountain cosmic ray station was founded. Since this time various cosmic ray experiments have been holding there. During one of the investigations called “Hadron-44” some halo events were obtained. In this article it was tried to compare the data obtained in the “Hadron-44” experiment with the Monte Carlo simulation using the CORSIKA program together with the GEANT4 toolkit.

2 Experimental data

The complex “Hadron-44” installation with an area of 44 m² consisted of an ionization calorimeter (IC) and an X-ray emulsion chamber (XREC) placed on it. The installation was mounted at a height of 3340 m above sea-level. The XREC of the “Hadron-44” installation was set upon the IC and covered its entire area of 44 m². The XREC was compounded with 2 layers of a lead absorber (3 cm and 1 cm thick) and interlaid with two rows of photo emulsions placed in lightproof box with dimensions of 0.5x1 m. More details on the instrumental setup and capabilities of this experiment can be found in previous publications [1].

We carried out investigations of air interactions recorded in the XREC with a total exposition of ST = 370 m² per year. With the use of the IC and XREC, we recorded two interactions with a primary energy level of above 10¹⁵ eV. They can be characterized by the existence of a “halo” in the XREC (“Sholpan” and “Anna”), and nuclear-electromagnetic cascades in IC. At observation level, the X-ray film (Type RT-6) and photo emulsion (Type R-2T) were used.

Figure 1: Halo “Sholpan”. A – isodences were drawn at levels of D = 0.7; 1.0; 2.0 and 3.0. B – the darkness density in the central part of the halo (spot cross-section).

To receive the various characteristics of registered halo events, a scanning of the films with an SI-2 helical scanner was carried out using Pamir experiment methods as
well as photometry with MF-2 and MF-4 photometers [2]. Halo “Sholpan” is illustrated in Figure 1 – A, B. The calculated energy in halo “Sholpan” by Vrotniak method was 4200 TeV [3]. The amount of energy in the electron-photon component of the halo by applying the method of track calculation was 690 TeV. For halo “Anna”, the energy values were 3240 TeV and 320 TeV respectively.

3 Simulation

3.1 Nuclear emulsion block

Generation and development of air showers was simulated by the simulation program CORSIKA [4]. Collisions in XREC were simulated by the GEANT 4 v9.2 [5] toolkit. CORSIKA was used to simulate air showers from primary proton with energies of $10^{16}$, $10^{17}$ and $5 \cdot 10^{17}$ eV. At observation level under XREC, the mean energy density distribution of gamma families was computed. A family was considered to be the distribution of gamma rays within 20 mm of the shower core. The number of gammas in the family and the total energy within a radius of 20 mm was also calculated.

The main characteristics of halos “Sholpan” and “Anna” are presented in the first three columns of Table 1. The first row shows the thresholds of nuclear photo emulsion for “Sholpan” and “Anna” events; the second – the number of gammas detected with nuclear photo emulsion; the third – the energy of events measured with nuclear photo emulsion. In the fourth, fifth and sixth columns, CORSIKA simulations with calculations within a radius of 20 mm are presented.

The result data of CORSIKA simulation was used in the GEANT4 toolkit to compute the flux density of electrons in XREC under a 4 cm slice of lead within a 20 mm distance from the shower core. Figure 2 shows that the radial distribution in halo “Sholpan” better corresponds to the simulation with a primary energy of $5 \cdot 10^{17}$ eV although we experimentally identified the primary energy as $(1-4.2) \cdot 10^{15}$ eV. The differences in 1.5 order shows that it is still difficult to explain these unusual events by simulation. As for halo “Anna” (figure 3), one can see that the distribution of the particle density does not correspond to the simulation and has flatter shape. However, if we take into account the fact that within a radius of

<table>
<thead>
<tr>
<th>Event characteristics</th>
<th>Sholpan</th>
<th>Anna</th>
<th>Corsika simulation (within 20 mm radius from the shower core)</th>
<th>$E_p=$</th>
<th>$E_p=$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy threshold of nuclear photo emulsion, GeV</td>
<td>0.3</td>
<td>0.5</td>
<td>Energy threshold, TeV</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Number of gammas by nuclear photo emulsion</td>
<td>497</td>
<td>77</td>
<td>Number of gammas</td>
<td>427</td>
<td>158</td>
</tr>
<tr>
<td>Energies by nuclear photo emulsion, TeV</td>
<td>690</td>
<td>20</td>
<td>Gamma quanta energy, TeV</td>
<td>696</td>
<td>513</td>
</tr>
<tr>
<td>Energies by RT-6, TeV</td>
<td>4200</td>
<td>240</td>
<td>Total energy, TeV</td>
<td>1568</td>
<td>1188</td>
</tr>
</tbody>
</table>

Table 1. Main characteristics of halo events

Figure 2: The electron density flux depending on the centre of the halo “Sholpan” (the experiment is shown as dots, the CORSIKA+GEANT4 simulation – continuous line).
less than 3 mm, considerable energy dissipation takes place causing the saturation of XREC films, we can predict more inclined spectrum and a higher energy of the halo in the center of a shower.

### 3.2 Ionization calorimeter block

A special interest has an experimental data, which was obtained in ionization calorimeter of the installation during the passing of the cascades which formed previously described halos in nuclear emulsion.

As it is seen in Figure 4 two cascades in different depths were observed in a calorimeter. One of the cascades was detected in the first layers of the calorimeter at 100-200 g/cm². The second was observed in the last layers at 1000 g/cm² and its maximum was situated out of the borders of the installation. Between two maximums a minimum at 650-700 g/cm² can be clearly seen and this can says about independency of these events. While first peak in calorimeter was generated by electro-photon cascade, which is also observed in nuclear emulsion, the second is the result of penetrating component interaction with a body of the calorimeter. The most probable cause can be muon interaction with calorimeter layers. We made Monte-Carlo simulation of muon penetration through the calorimeter body. Considering the probability of muon decay, ionization, radiative, bremsstrahlung, pair production and nuclear reactions two energy intervals 500 MeV ÷ 5 GeV and 500 GeV ÷ 10 TeV was chosen. The simulation was held with the use of Geant4, where the model of installation was created. For each muon primary energy a 1000 beams was made and a differential curve of muon energy loses was plotted. It was founded that the mean energy loses don’t explain the experimental curve. But among 1000 beams of TeV energies there were about 0.5% peak events which can be associated with experimental data (figure 5).

### 4 Conclusion

The simulation satisfactorily describes halo “Sholpan”, which is generated by a primary proton with an energy of $5 \times 10^{17}$ eV, although this energy extremely exceeds the experimental one. Halo “Anna” doesn’t correspond to simulation. Its spectrum runs higher than the curve of the primary hadron with an energy of $5 \times 10^{17}$ eV. Taking into consideration the strong dissipation that caused the saturation of the XREC films in the centre of the halo [6], halo energy can be appreciably higher. As for anomalous events in ionization calorimeter they can be hardly explained by high energy muons.

### 5 References

[2] S.G. Baburina, A.S. Borisov, Z.M. Guseva, and Associates, Pamir collaboration, study of nuclear interaction of cosmic rays in the energy range of $10^{14}$-$10^{17}$ eV by the