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Simulated properties of HALO events observed at the pamir experiment

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Abstract. We show results of calculations for halo events measured at the Pamir experiment. The calculations have been done for proton-initiated showers. We have used the CORSIKA program with the QGSJET model for the simulations of the air-shower development in the atmosphere. The area of the “halo” in an X-ray calorimeter has been calculated with the use of the GEANT program. The properties of “halo” events as well as the correlation between the initial energy of the primary particle and the calculated area of the halo are presented. The simulation shows that the contribution of the secondary hadron component into the visible area of the “halo” at the Γ-block is negligible.

1 Introduction

The main goal of the present paper is to show (preliminary) results of halo calculations for a high-altitude calorimeter using the detector simulation tool GEANT (Cern, 1994). A full and detailed Monte-Carlo simulation for the Pamir X-ray chamber has been done and effects of factors, which were never investigated in previous simulations can be discussed.
For a few recent years the phenomenon of ”halo”-events (Pamir collaboration, 1984), observed in X-ray calorimeters exposed to measure cosmic rays on mountain altitudes has been attracting the attention of many researchers. An X-ray chamber in a calorimeter consists of a sandwich of lead, X-ray films, and carbon layers. The detailed construction is described in (Pamir collaboration, 1984). In such a typical calorimeter structure an upper part (called the Γ-block) registers individual photons, electrons and positrons of energies larger than 2 TeV (in average) above the chamber. Each of these particles create an electromagnetic cascade in lead. Plates of X-ray films are placed below 4, 5 and 6 cm of lead. Although all layers of the film are processed, the layer below 5 cm is considered as the main one for the present analyses. The lower part of the calorimeter (if existing), consists of a thick layer of carbon and lead as additional absorber and is called the hadron block. In the hadron block secondary hadrons pass through the chamber and can interact, and the tracks of their interactions can be seen in the X-ray plates located between lead below the carbon. The set of cascades of particles from a single EAS and observed in a X-ray film is called a “family”.
In the present paper we consider only events observed in the Γ-block. For high-energy families with reconstructed energy sums larger than 400 TeV (in the Γ-block) we observe events with a large dark spot, exceeding the dimensions of individual cascades. This dark spot is called “halo”. It was shown that halos are created by the bunch of particles very close to the EAS axis. At the Pamir experiment more than 60 halo-events (to be defined further) have been registered. However, the most famous observed event was the first one, called Andromeda and found at the Chacaltaya experiment. Since the registration of Andromeda, more than 5 events of comparable size have been found at Pamir. Their areas exceed $1000\,\mathrm{mm}^2$ (Borisov et al., 2001).
An actual problem is that the number of halos with areas greater than $100\,\mathrm{mm}^2$ is too high (Borisov et al., 2001) in comparison to simulations. In the calculations, both the composition and energy spectrum of primary particles for the high-energy region are extrapolated from the lower range of their values. In (Borisov et al., 2001) it was shown that the change of the composition in wide, generally acceptable range could not explain the discrepancies in the intensity of the calculated and experimental data.

2 Simulations in the atmosphere and in the calorimeter

The CORSIKA program (Heck et al., 1998) has been used to simulate the development of the extensive air showers at the atmosphere, including the QGSJET (Kalmykov et al., 1997) model for the high-energy nuclear interactions. The model was chosen as it fits best the existing cosmic ray data (Antoni et al., 1999). The adapted cross sections for nuclear interac-

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tions are in agreement with the model. For the present simulations primary particles entering the atmosphere are generated with an power law spectrum of a slope of -2.8 in the range of $5.10^{16} - 5.10^{17}$ eV. Zenith angles vary from 0 to 40 deg. All particles are traced down to the energy threshold $E_{thr} = 100$ GeV. This energy threshold is sufficient for studying the properties of γ-hadron families. However, for the purpose of simulations of halo-events it is the upper permissible value. As it was shown in (Iwan and Krys, 1999) the area of halo can be underestimated by about 10-20%, due to the missing particles of lower energy which still contribute to the spot. The used threshold value is the compromise between the calculation time for the simulation in the X-ray chamber and the accuracy of the calculations.

There are several methods of the simulation of the particle transition through a X-ray chamber: by the use of a half analytical – half Monte Carlo approach (Dounaievski, 1990), as well as by full Monte-Carlo approach (Krys and Krys, 1999). In this paper the results of a full Monte-Carlo calculation with the GEANT program (Cern, 1994) are used. All kinds of particles (output of the CORSIKA program at the observation level of the Pamir experiment) which enter the chamber, have been processed by GEANT. To reduce the time of calculations, only particles within a radius of $120\,\mathrm{mm}$ of the shower axis are taken into account. As it is shown below, this limitation is fully justified.

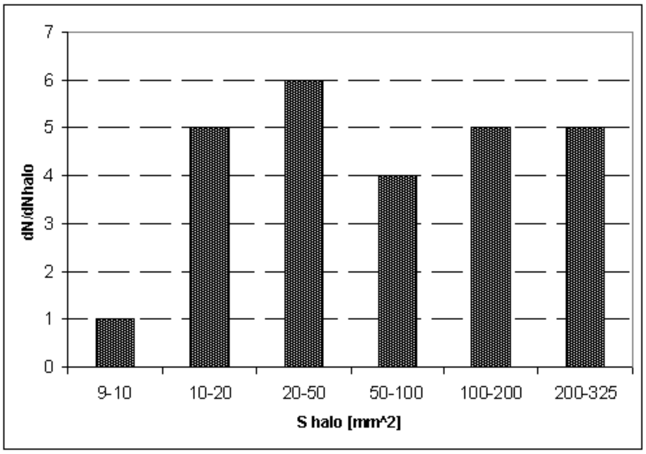

Fig. 1. The differential distribution of the halo area.

The following phenomenological criterion has to be fulfilled for the acceptance of a halo-event: the area S, limited by the isodense with the optical darkness density $D = 0.5$ at one layer of X-ray film (under 5 cm of lead) have to be larger than 4 mm^2. The halo darkness $D = 0.5$ corresponds to the particle density 0.04 per μm^2.

For each event the density of electrons and positrons passing through the main X-ray film (under 5 cm of Pb) was calculated with GEANT. For that, the surface of the X-ray film was divided into a chess board-like cell matrix, for each cell the number of electrons and positrons are summed up for all particles entering the calorimeter. Then the density at each cell was calculated. The side of a squared cell was chosen to $0.2\,\mathrm{mm}$, leading to an area resolution of the density (i.e. darkness or optical density) of $0.04\,\mathrm{mm}^2$.

3 Results

The obtained results are based on 50 full simulated cores of proton initiated EAS. For 26 cores of the processed EAS a halo was found. In two events a multi-core halo was observed. To accelerate the calculations in the calorimeter, only those particles were taken into account, which fell within a radius of less than 120 mm of the EAS axis. In order to check the validity of this cut the distances of the density weighted center of the halo to the axis of the primary particles are calculated. The results are shown in the Table 1. The lack of halo events at distances larger than 40 mm confirms that the supposed radial cut-off do not affect the creation or area of a halo. The cut is necessary to decrease of the number of the particles which have to be processed by GEANT. In the present simulations, still the number of input particles for GEANT are up to 70,000, making the calculations very time-consuming.

dist. from the axis of prim. part. [mm]	$0 - 10$	$10 - 20$	$20 - 40$	> 40
no. of halo events	18	5	3	0

Table 1. The distance of the center of the halo from the EAS axis.

The distribution of the calculated halo areas is shown in Fig. 1. The areas are in a range of $(9.8 - 325\,\mathrm{mm}^2)$ The lack of events with small area is caused by missing lower energies of primary particles in the simulations. In our simulations we concentrate on properties of the halos, which were initiated only by high energetic primaries - it was shown before (Guseva et al., 1999) that protons of energy below (5.10^{16}) eV still can create halo, even though with small probability. But please remember that in our considerations due to the threshold of secondary particles the size of the halo can be underestimated of 10-20%.

The probability of creating a halo with an area greater than $100\,\mathrm{mm}^2$ by protons of the considered range of primary energy is estimated to 0.2. This value does not contradict the results presented in (Borisov et al., 2001), where the calculations of the halo area were obtained by the use of the ”isodense” method.

In Fig. 2 the dependence of the halo area with the energy of the primary proton is shown. We suppose that a primary proton with energy higher than 200 PeV should create a halo in the Γ-block of the Pamir calorimeter with a probability close to 1.0. The dispersion of halo areas for the highest energies in the considered range is significant. Let us consider two high-energetic events in more detail: their primary proton energies are 380 and 465 PeV and their halo areas are $42\,\mathrm{mm}^2$

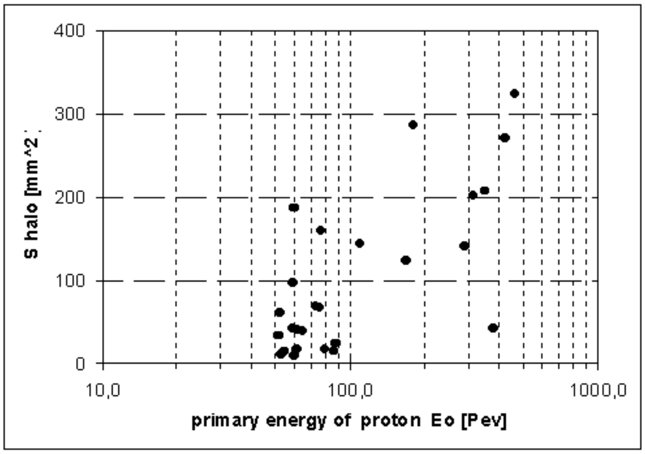

Fig. 2. The dependence of the halo area with the energy of primary particle.

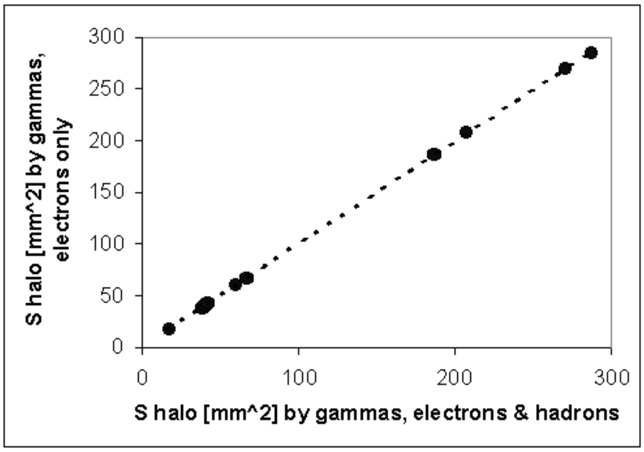

Fig. 3. The area of halos calculated for all particles entering the calorimeter versus the area calculated for the case where only gammas and electrons are taken into account.

and $325\,\mathrm{mm}^2$, respectively. The limited statistics does not let us draw quantitative conclusions but an error of one order of magnitude seems possible, if the energy of the primary particle is estimated based on the halo area.

The use of GEANT gives the possibility to estimate the contribution of individual particle components, i.e. hadrons and γ/electrons, to the area of halo events created in the gamma block. Although the number of hadrons above the chamber, which can contribute to the halo area are about 2% of γ/electron numbers, a non-confirmed conviction exists that hadrons interacting early in the lead of the Γ-block make a non-negligible contribution to the area and darkness of a halo. To solve this problem, we calculated for a few events the densities of electrons passing through the X-ray film for the hadron and for the γ/electron component separately. Therefore we can calculate the contribution of secondary hadrons to the area of the halo. The correlation between the halo area due to all particles (X-axis) and the halo area caused only by the γ/electron component (Y-axis) is presented in Fig. 3. A very good agreement between the halo areas caused by the γ-electron/positron component and that of all particles is obvious. The best linear fit for this dependence is (0.99 ± 0.13). The results show that the contribution of the hadron component into halo creation in the Γ-block is negligible.

4 Conclusions

With sophisticated tools like the air-shower simulation program CORSIKA and the detector description code GEANT it was possible to reconstruct events with a halo core structure as measured in the Γ - block of the X-ray calorimeter at the Pamir emulsion experiment. Detection efficiencies and halo areas from that simulations are in agreement with the measurements.

As a main result we could show that the contribution of the secondary hadron component into the creation of the halo area is negligible. Additionally it was found that the spread of the reconstructed halo area for a considered range of primary energies is very large. Hence we conclude that the estimation of the primary energy of the proton initiated air shower from the area of the halo seems to be impossible.

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