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Halo-like events - cosmic ray interactions

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Abstract. The emulsion chamber, a multiple sandwich of lead plates and sensitive layers (X-ray films and/or nuclear emulsion plates), is a detector of electron showers which are produced in the chamber through cascade process by incident photon or electron/positron. The recent results of emulsion chamber experiments include the highest energy events named ”halo”. Most of the results presented below were obtained from fixed experimental devices and with calculations made especially for them. The Monte-Carlo simulations both physical process and features of definite experiment have been taken into consideration.

1 Introduction

Both the composition and the energy spectrum of primary particles in the range of PeV to EeV are still one of the fundamental and unanswered questions in physics of cosmic rays. The astrophysical problem connected with the search for point sources (the search of anisotropy) plays a crucial role in the investigation of cosmic ray particle interactions with atmospheric nuclei. It should be emphasized that of the existing experiments it is not possible to disentangle fully the particle physics from astrophysical implications of extensive air showers (EAS). In order to extract information on both the origin and the primary composition of cosmic rays from observations, one has to have a complete understanding of particle physics, which dictates the development of cascades in the atmosphere. In the energy up to $10^{17}eV$, which can be converted by accelerators, the results of elementary particle physics are comparable for both techniques: accelerator beams and cosmic rays. Direct observation of the nuclear interactions of $E > 10^{17}eV$ is not easy due to the low intensity of high energy cosmic rays. The steeply falling fluxes allow only indirect measurements at ground level. An important feature is the identification of a particle from the measured final state.

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2 Detectors

Emulsion chambers are widely known as detectors for high energy showers. At Mt.Chacalataya (5200 m a.s.l.) and Pamir Mountain (4300 m a.s.l.), the emulsion chamber experiments have been carried out, aimed mainly at studying nuclear interactions in the energy regions exceeding those of the accelerators. The basic element of a large emulsion chamber is a sandwich of lead plates (each about 1 or 2 cm thick) and X-ray films/or nuclear emulsion plates. The X-ray films in these devices register an incident energetic photon or electron, which initiates electromagnetic cascades in lead. Recent results of the emulsion chamber experiments include two kinds of unusual events named ”halo” and ”Centauro”, which are hard to be explained by accidental fluctuations. ”Halo” is a dark spot of several tens of sq. mm in area, which can easily be seen with an unarmed eye on X-ray film.

”Centauro” - the events of multiple productions of charged particles accompanied by very few photons. At present, none of the hypotheses can describe the ”Centauro” events fully and convincingly.

3 Simulations

Primary cosmic ray particles such as (γ, p or Fe) with the Eo incident energy upon the atmosphere, producing a large number of electromagnetic and nuclear cascades. Emulsion chamber experiment can register only high energy particles $E > 0.3$ TeV. Both unusual events mentioned above require detailed numerical calculations of EAS development in the atmosphere and then in the emulsion chamber. Since the number of final state particles is often very large, efficient approximation as well as simulation techniques have to be applied to calculations for the measured data or for the study of theoretical predictions. While assumptions of electromagnetic interactions are accurately calculable in QED, the major uncertainties arise from the hadronic interaction, which is usually described by a phenomenological model. Two

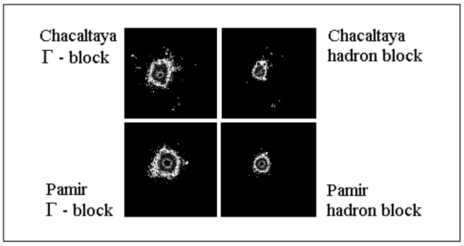

Fig. 1a

Table for Fig. 1a Eo=1.27*10^{17}eV		
	Γ-block	hadron block
Chacaltaya	Ne=6.07*10^{7} S=190 mm^{2}	Ne=2.69*10^{7} S=77 mm^{2}
Pamir	Ne=6.12*10^{7} S=207 mm^{2}	Ne=2.38*10^{7} S=77 mm^{2}

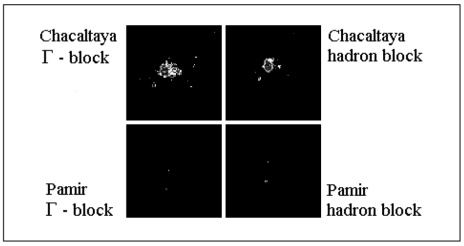

Fig. 1b

Table for Fig. 1b Eo=1.25*10^{17}eV		
	Γ-block	hadron block
Chacaltaya	Ne=2.24*10^{7} S=55 mm^{2}	Ne=1.51*10^{7} S=40 mm^{2}
Pamir	Ne=7.90*10^{6} S=1 mm^{2}	Ne=3.59*10^{7} S=1 mm^{2}

Fig. 1. Eo is primary proton energy; Ne - number of particles with 2 MeV threshold registered on observation level; S - the area of ”halo”.

groups of assumptions have been made with respect to our simulations. One is connected with the EAS development in the atmosphere. The other deals with the EMC development in a chamber (lead, carbon and emulsion) and with the conditions of ”halo” registrations. The description of the assumed models of nuclear interactions from the Corsika, the QGSJET model, can be found in (Heck et.al., 1998).

Primary particles that enter the atmosphere are sampled with constant energy, but the zenith angles vary from 0 to 40 deg. Every run is made for proton at the primary energy from the interval of $8 * 10^{16} - 3 * 10^{17} eV$. In our calculations hadrons are traced down to the energy of 0.02 TeV and the same threshold is applied to gammas and electrons/positrons. Each run progressively produces electrons and photons as they move down through atmosphere to the depth of Chacaltaya and Pamir locations.

The simulations of EMC propagation through the multilayer chamber (a sandwich of many sheets of Pb/C and X-ray emulsion) are based on detailed modeling of the three dimensional particle propagation. All the electromagnetic processes (radiation, pair creation, inelastic scattering of electrons and positrons with the productions of delta electrons, the Coulomb scattering, the Compton effect, ionization losses, LPM effect) in which the particles can be involved are considered with the energy threshold of 2 MeV for secondary electrons and photons.

The assumed structure of the chamber is similar to that of a large γ - hadron detector used in cosmic ray calorimeters at mountain level. The chamber in simulations, has two parts: the upper consisting of 6 cm of Pb (Γ - block) and the lower, consisting of 60 cm carbon and 5 cm of Pb (hadron block). The sheets of X-ray films are located under 5 cm in upper lead and 5 cm in lower lead. The ”EKAW” program (A.Wasilewski et.al.,1988) and (E.Krys et.al.,1999) with modifications by A.Krys was used for the simulation of passing the electromagnetic component of EAS through the X-ray calorimeter.

4 Simulations and Experiments

The following phenomenological quantitative criteria of ”halo” existence have been accepted: the area S bounded by the isodense line with optical density of darkness D=0.5 is greater than or equals 4 sq.mm. In the experiment we used the conventional methods to identify hadronic cascades,namely cascades observed below 10 c.u.in the upper chamber and cascades registered in the lower chamber only.

5 Results

Typical pictures of ”halo-like” events were chosen from the set of our simulations for two pairs of proton showers, with similar primary energies:

$Eo = 1,27 * 10^{17} eV$ (Fig.1a),
$Eo = 1,25 * 10^{17} eV$ (Fig.1b)
and
$Eo = 2,32 * 10^{17} eV$ (Fig.2a),
$Eo = 2.21 * 10^{17} eV$ (Fig.2b).

The proton showers were simulated in the atmosphere down to the Chacaltaya and Pamir observation levels and then processed in the X-ray calorimeter, giving ”halo-like” events in Γ and hadron blocks. The same run of CORSIKA program (with same origin of random generator) was first performed for Chacaltaya and then for Pamir. The relation between the energy of primary proton and the probability of ”halo” existence was tested for each run (in the simulations in the X-ray calorimeter we didn’t consider the processing of hadron component either in Γ or in hadron blocks).

We present two different stages of proton shower’s development in the atmosphere ; the areas of darkness of the registered ”halo-like” events have different sizes (see Figs and Tabs).

The upper two pictures in each figure represent the cores calculated for Chacaltaya observation level, while the lower ones are for Pamir observation level. The same EAS cores

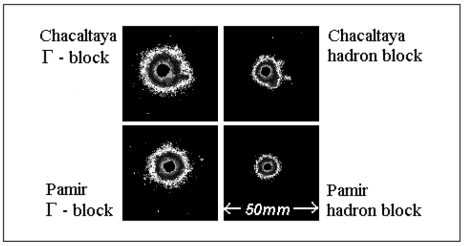

Fig. 2a

Table for Fig. 2a Eo=2.23*10^{17}eV		
	Γ-block	Hadron block
Chacaltaya	Ne=1.40*10^{8} S = 552 mm^{2}	Ne=6.52*10^{7} S = 228 mm^{2}
Pamir	Ne=1.14*10^{8} S = 400 mm^{2}	Ne=4.51*10^{7} S = 140 mm^{2}

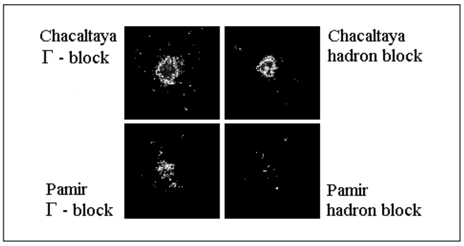

Fig. 2b

Table for Fig. 2b Eo=2.21*10^{17}eV		
	Γ-block	Hadron block
Chacaltaya	Ne=4.55*10^{7} S = 143 mm^{2}	Ne=2.68*10^{7} S =87 mm^{2}
Pamir	Ne=2.81*10^{7} S = 42 mm^{2}	Ne=1.47*10^{7} S = 8 mm^{2}

Fig. 2. Eo, Ne, S described same as for Fig.1.

are shown in each row for the Γ - block (left hand-side picture) and hadron block (right hand-side one) , for each run.

We would like to draw your attention to the fact, that "halo-like" events are registered both in Γ and hadron blocks.

The number of particles creating "halo" in hadron block (below 5 cm of Pb, 60 cm of C and 5 cm of Pb) is only about 50 % smaller than in gamma block (below first 5 cm of Pb).

On the other hand, both in Γ and in hadron blocks we observed "halo-events" of similar sizes of darkness, created by the proton cascades, first with the energy $Eo = 1.25 * 10^{17} eV$ and twice that big $(2.21*10^{17} eV)$ (Fig.1a and Fig.2b), for Chacaltaya observation level.

Most detailed studies on the fluctuations of proton cascade development in the atmosphere show, that the energy threshold for primary proton which creates "halo-like" event is $8 * 10^{16} eV$ for Pamir and $5 * 10^{16} eV$ for Chacaltaya observation level.

6 Conclusions

The results of EAS simulations both in the atmosphere and X-ray calorimeter (EMC in lead, carbon and emulsion) for primary protons of energies above $5 * 10^{16} eV$ show, that

-The electromagnetic component of EAS creates "halo-like" events in Γ and hadron blocks. As it is known, "halo" registered in hadron block is interpreted as hadrons.

-The estimation of primary energy values is not obvious-since the fluctuations of development in the air affect significantly on the registered areas of darkness of "halo-like" events.

The negligence of fact, that an electromagnetic component is able to create "halo" in hadron block leads to false estimation of primary particle's energy and to misinterpetation of nuclear interactions. Then the flux of intensity of primary particles may be calculated with a significant error.

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