OG.1.3.11

Cosmic gamma-rays and cosmic ray particles

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Abstract

Emulsion chambers have been used for about 50 years in the field of cosmic rays physics as detectors of cosmic rays. At mountain altitudes high energy γ-ray bundles can be observed in the central part of an air shower. The recent results of emulsion chamber experiments include highest energy events named "halo" and "Centauro". Most of the results presented below were obtained from fixed experimental devices and with calculations made especially for them. In Monte Carlo simulations both physical processes and features of definite experiment have been taken into consideration.

1 Introduction

Discovering of origins of the highest energy cosmic rays has been a goal in astroparticle physics since the first reported detection of a particle with energy greater than 100EeV (10^{20}eV) (Linsley 1963). Detection of $3*10^{20}$eV cosmic ray by the Fly's Eye detector, well beyond the expected cutoff, has posed a puzzle as to its origin. The arrival direction of the 320EeV particle does not point to any obvious source within a distance limit less than 50Mpc. The source candidates of such energetic particles are very powerful radio galaxies, which can be located within the error boxes of the events, all being more than 100Mpc away. There are some reasons to believe that gamma ray flux may exist at extremely high energies. In case of extra galactic origin of cosmic rays their interactions with MBR transfer a significant fraction of their energy to photons so then EHE photons may dominate the all-particle cosmic ray energy spectrum above 10^{20}eV. The EHE photons may develop an electromagnetic cascade in the Earth's magnetic field. Monte Carlo simulations of development of an EHE photon initiated electromagnetic cascade in the geomagnetic field has been performed by Karakula (1995). The cascade curves of showers formed in the Earth's magnetic field are superposition of many lower energy electromagnetic air showers initiated by the cascade particles. The mean energy distribution of secondary photons formed in course of the cascade development (initiated by a primary photon of given energy $E>10^{19}$eV) in the Earth's magnetic field depends on the geographic latitude (of the site of the installation) and the direction of the primary particle (the zenith angle and the azimuth angle). The photons are emitted within an extremely narrow cone (energies of secondary particles are 10^{15} to 10^{18}eV).

The puzzle of missing sources can be solved alternatively if it is assumed that the particle was not accelerated at any astrophysical object; there may be a new physics or astrophysics to learn from. Elementary particle physics in both accelerator and cosmic ray aspects is comparable regardless the reference system (beams or laboratory system). Particle accelerators in operation and under construction will cover equivalent laboratory energies up to 10^{17}eV. The energy beyond 10^{17}eV is reserved for high energy physics of cosmic rays. An important feature is an identification of the particle from the measured final state there. It should be stressed that on the basis of so far existing experiments it is not possible to disentangle particle physics from astrophysical implications of extensive air showers (EAS). Widely known as a detector for high energy showers (Chacaltaya, Pamir) is an emulsion chamber. The recent results of emulsion chamber experiments include the highest energy nuclear events named "halo" and "Centauro". Usually, when the emulsion chamber is hit by the core of an air shower a bundle of gamma rays and hadrons, which is called a family, is detected in the air shower. Identification of the showers which have contributed to the family is easy because they have the same azimuth angles on the map where trajectories of all the showers are projected onto a horizontal plane. Primary cosmic rays always produce clearly visible families in the region $E>2*10^{16}$eV. A phenomenon called „halo” is observed as blackening of X-ray films around the family center. It is a routine procedure in emulsion chamber experiments to measure spot darkness within the grid of certain size (400*400 μm) with the use of a microphotometer and then to estimate each shower energy throughout the transition curve. Photo-sensitive layers, inserted at various depths in the chamber, can observe various stages of development of the shower.

The highest energy event „Andromeda” is presented in Fig 1 (Fujimoto 1993).

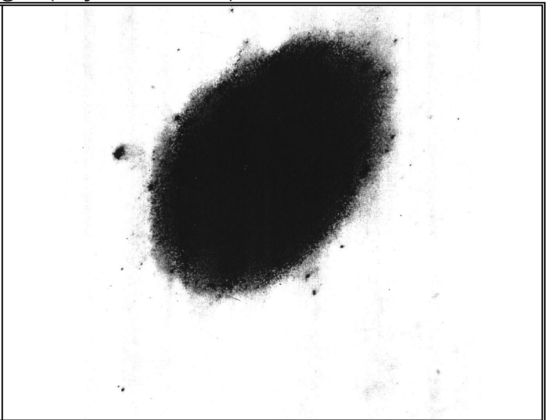


Fig. 1: Andromeda; Contribution from Chacaltaya emulsion chamber experiment of Brazil – Japan collaboration (area about 50-60cm^2). The event penetrated the whole thickness of the chamber.

The „Centauro” events are results of multiple production of charged particles accompanied by very few photons. “Centauro” events are registered in the two experiments mentioned below with different probabilities as the threshold energy of hadron observation at Pamir is about 7-10TeV while for the Chacaltaya experiment it is ~0.5TeV because of the use of nuclear emulsion. The fraction of “Centauro” events in the Chacaltaya experiment is 1 event per year for the exposure ~100m^2.

2 Assumption for simulation data

The present paper is devoted to the estimation of the energy of the primary particles which may create halo and “Centauro” events. We believe that the electromagnetic cascade processes are completely understood on the basis of QED. Two groups of calculations were carried out: one was connected with the development of the electromagnetic cascade in the atmosphere, the other dealt with its development in a chamber (lead carbon and emulsion). There were three series of runs for gamma induced showers in air with primary energies 10^{17}, 10^{18} and 10^{19}eV. Each run progressively produced electrons and photons as they moved down the atmosphere to the depth of Pamir. The results of the simulations for the air showers with primary energy $Eo=10^{18}$eV are presented in the form of a lateral distribution of secondary particles (electrons and photons; E_{THR}=0.5TeV) at the Pamir level (Tab. 1).

Table 1: Lateral distribution of secondary particles. $Eo=10^{18}$eV, E_{THR}=0.5TeV.

$Ep=1.094*10^{18}eV$		$N_{total}=154436$		$E_{ph,e^+,e^-}=3.120*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
116832	131237	139135	143775	146732	148630	149979
$Ep=1.017*10^{18}eV$		$N_{total}=122018$		$E_{ph,e^+,e^-}=2.437*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
90571	102747	109087	112926	115359	116991	118099

$Ep = 1.083*10^{18}eV$		$N_{total} = 143271$		$E_{ph,\,e^+,\,e^-} = 3.411*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
108515	121083	127922	131911	134538	136270	137596
$Ep = 1.050*10^{18}eV$		$N_{total} = 131607$		$E_{ph,\,e^+,\,e^-} = 2.842*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
94271	108756	116462	121007	123785	125720	127072
$Ep = 1.074*10^{18}eV$		$N_{total} = 141128$		$E_{ph,\,e^+,\,e^-} = 2.995*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
104841	118953	126518	130950	133791	135679	136938
$Ep = 1.061*10^{18}eV$		$N_{total} = 141242$		$E_{ph,\,e^+,\,e^-} = 3.896*10^{17}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
110923	123168	129347	133169	135411	136962	137904
$Ep = 1.031*10^{18}eV$		$N_{total} = 54947$		$E_{ph,\,e^+,\,e^-} = 8.398*10^{16}eV$		
1cm	1.5cm	2cm	2.5cm	3cm	3.5cm	4cm
29580	38846	43937	46866	48924	50302	51312

The data show that a stream of secondary particles in the air just above the emulsion chamber is very narrow, ie. its range is up to 4cm. Having entered the chamber all the particles initiate electromagnetic cascades in lead and carbon what leads to darkening of the X-film.

3 Results

A high energy particle of electromagnetic component (electron or photon), when reaching the chamber, produces electromagnetic showers in it through the cascade processes in lead and carbon plates. The simulations of the EMC propagation in the multilayer system (a sandwich of many sheets of Pb-C and X-ray emulsion) were based on the detailed modelling of three dimensional propagation of the particle. All processes were considered in which the particles could have been involved. Our simulation results for γ and proton showers were shown at the Gran Sasso (E.Krys 1998). The assumed structure of the chamber with one layer of carbon was similar to that of the large gamma-hadron detectors which were used in cosmic ray calorimeters at the mountain level. The examples of the haloes created in the chamber are presented in Fig.2. As one can see, the cascade initiated by a primary photon with energy above 10^{17}eV passes the whole structure of the chamber and produces "haloes" at several levels of the chamber. The darkness of a "halo" may have a shape of a circle (or ellipse) the area of which depends on the primary energy of the particle. The darkness of the center of the cascade reaches D_{max}. It cannot be ruled out that a primary particle which has created a halo (of the area>1cm^2) may be a charged particle of energy about 10^{18}eV. It seems that ‘Andromeda’ could have been intitiated by a primary with energy above 10^{19}eV. An attempt to interprete Centauro events as the events of registered superpositions of lower energy photons, created as a result of interactions of high energy photons with the Earth’s magnetic field has not been successful at Pamir level up to present. The calculations ought to be repeated for the Chacaltaya level with regard to a right structure of the chamber.

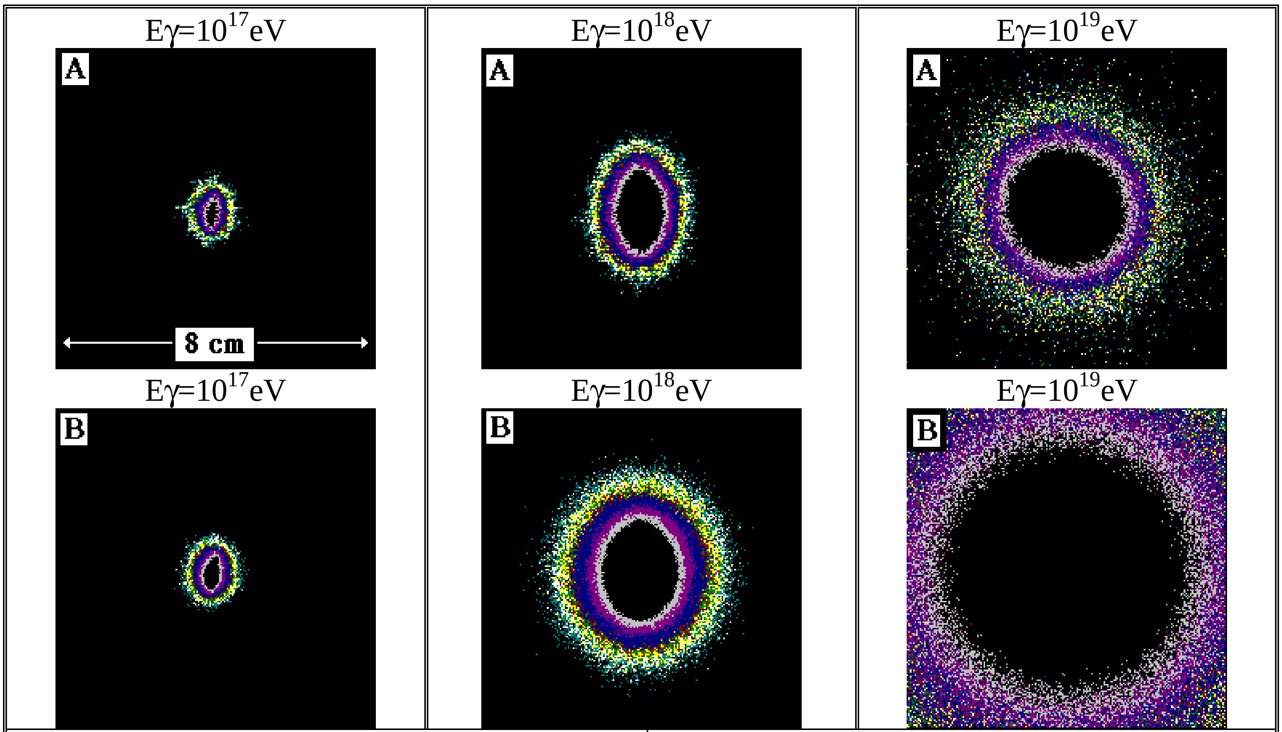
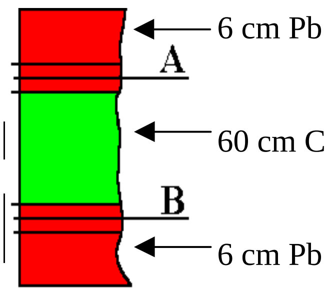


Fig. 2:
The assumed structure of the chamber with one layer of carbon. The darkness of a „halo" (D=0.5); upper chamber after 5cm Pb (10^{17}eV-1.5cm^2, 10^{18}eV-7cm^2, 10^{19}eV-20cm^2); lower chamber after 6cm Pb +60 cm C+ 5 cm Pb (10^{17}eV-2cm^2, 10^{18}eV-16cm^2, 10^{19}eV-60cm^2)



4 Summary

The results of the complete simulation of development of the EAS in the air and then the induced electromagnetic cascades in the emulsion chamber show that the registered events of haloes do not require that some exotic processes should exist in interactions of particles of the highest energies. Some additional calculations at Chacaltaya level with regard to a proper structure of the chamber ought to be carried out in order to make it possible to interprete Centauro events. Such calculations are enormous time-eaters, however, on the other hand, they are very important for our comprehension of elementary particle physics and astrophysics.

We acknowledge support by the Rector of the University of Lodz (Grant 504/163).

5 References

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