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The first results obtained with the installation HORIZON-T

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A new installation HORIZON-T is commissioned at the high altitude scientific station of P.N. Lebedev Institute at the Tien-Shan Mountains. The purpose of this installation is to study EAS arriving at the zenith angles close to the horizon. The installation consists of three Vavilov - Cherenkov detectors located at the center of the installation and five registration points for muons which are placed within 500 m from the center. With the help of HORIZON-T installation EAS events have been detected at zenith angles more than 65 degrees, some of which had muon pulses with the front being ahead of one from Vavilov – Cherenkov pulses by more than 20 ns. Simulations show that such EAS are most likely initiated by primary nuclei with the mass more than 10.

1. Introduction

Currently a new installation HORIZON-T has been created and launched into operation at TSHVNS LPI Russia, located near the city of Almaty, at an altitude of 3340 m above sea level. The unit is designed for the study of showers arriving at angles close to the horizon. The possibilities which provides simultaneous registration of arrival times of Vavilov-Cherenkov radiation and charged particles in the individual horizontal shower to study characteristics of primary cosmic particles and their interactions at energies above 10^{16} eV are discussed in [1-4]. Installation model of the HORIZON-T was created and operated in 2006-2009; its results are presented in [5].

2. Installation

The installation HORIZON-T (figure 1) consists of scintillation counters (SC) system and optical one. The SC-system is intended to detect EAS charged particles, it contains 17 plastic detectors (1 m×1 m×5 cm), the light flash from SC being registered by PMT (FEU-49B). All detectors are distributed over the registration points which are marked by numbers in figure 1. Point “1” is the centre of the system and contains 4 SC-detectors.

The location of the points "2", "3", "4", "5" relative to the centre and number of detectors in each of them are respectively: 460 m to the South (8 detectors), 420 m to the North (one detector), 120 m to the West (two detectors), 150 m to the East (two detectors). In each point the signals from all detectors are summarized. Signals from each point are sent to the registration center, located in the point "1" and received by 3 oscilloscopes Tektronix TDS-2014B. Each of the received signals is stored for 8 microseconds (time gate). A trigger is generated if during the "time gate" the pulses from the points of "1", "4", "5" exceed the specified electronic thresholds. The trigger starts the recording of signals from all of HORIZON-T detector points.

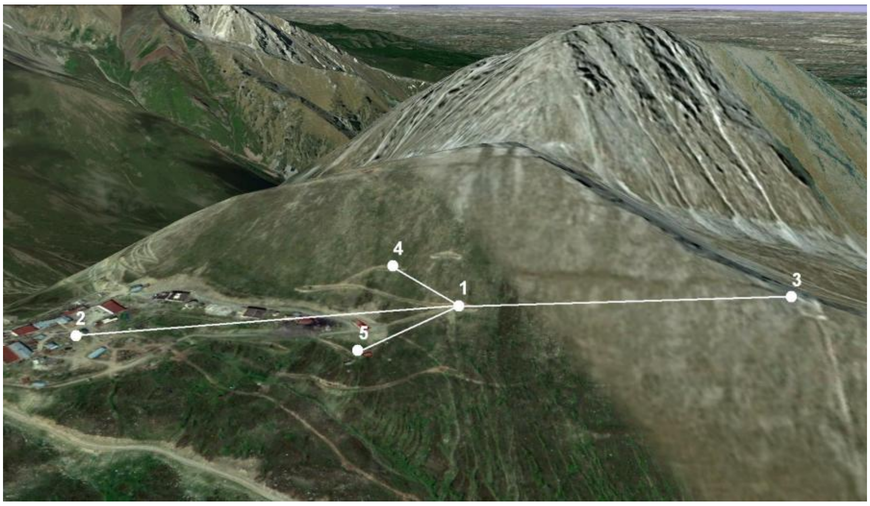

Figure 1. Scheme of HORIZON-T installation.

The southern half (points "1", "2", "4", "5") of the installation works if the primary particle energy is $E_0 < 10^{17}$ eV, as the southern half of the set includes point "2" with a total area of SC-detectors equal to 8 m^2. The aperture of the southern half is of 0.5 km^{2}sr. The entire array with the point "3" works if the primary particle energy is $E_0 \geq 10^{17}$ eV, the aperture being up to 1.0 km^{2}sr.

The optical system is located in the centre of the array and consists of 3 parabolic mirrors with a focal length of 65 cm and 150 cm in diameter, mounted on the rotary device. Rotator allows us to register Vavilov-Cherenkov radiation within directions from 0° to 80° for zenith angles and 0° to 360° for azimuthal ones. In the foci of the mirrors there are photomultipliers FEU-49B or FEU-65. The photocathode diameter of the PMT is 15 cm, so the visibility angle of each mirror is 13°.

Unlike the SC-detectors, which are all-weather ones, the optical system is able to record the Vavilov-Cherenkov radiation only in clear moonless nights. At such nights the trigger is generated if the signal level from FEU-49B of one of the mirrors exceeds the mean-square fluctuations of the background night sky six times. This trigger starts the recording of signals from all HORIZON-T detectors.

3. Results and discussion

Up today (May 2012), scintillation system has worked for 520 hours, 3124 events were detected. Preliminary processing of the experimental data shows that the threshold of SC-detector system is $5 \cdot 10^{16}$ eV.

Systems of SC-detectors and optics have worked for 120 hours together in 2011-2012. The axes of the mirrors have been directed at the zenith angle of 70° towards the East. The recorded EAS had zenith angles 65° - 75°. At present the collected experimental data are in processing and analyzing. One of the problems of processing of this material is the intercalibration of two methods of determining the energy of the primary particle that generates the shower:

1) according to the lateral and time distributions of charged particles;

2) from the Vavilov-Cherenkov radiation.

Among the events were detected at zenith angles 65-75 degrees, some events had SC pulses at point “1” with the front being ahead of one from Vavilov – Cherenkov pulses by more than 20 ns. Figure 2 shows an example of the event when the particles come to the installation before the Vavilov-Cherenkov radiation at 27 ns. The energy of the primary particle was estimated by the pulses from the Chrenkov radiation as approximately equal to 10^{17} eV.

Ultra-relativistic particle with mass m and energy $E >> m$ moving in a medium moves with a velocity practically equal to the speed of light in vacuum c. A photon in a medium with a refractive index n has a speed equal to c/n. Let a particle and a photon emitted simultaneously from a single point. After the passage of air layer Q (in g/cm^2) ultra-relativistic particle is ahead of a photon in the atmosphere at the time τ, which can be estimated by the formula (Beisembaev, Vildanov [6])

$$\tau = \frac{Q}{125.5}\ \text{ns}\,. \tag{1}$$

After passing of 300 g/cm^2 of atmosphere the EAS with energy 10^{17} eV emits at the mean photon flux, causing the light pulse exceeding the threshold of detection, which is determined by the background night sky. This estimation agrees with experimental data obtained at the Yakutsk complex installation [7].

At the 70° zenith angle the amount of air from the boundary of the atmosphere to the observation level (3340 m above sea) is about 2000 g/cm^2. Consequently, the photons of the front of the Vavilov-Cherenkov radiation pass 1700 g/cm^2 in atmosphere.

We assume that the particles overrunning the photons of Vavilov-Cherenkov radiation and are recorded by SC-detectors are muons from pion decay from the nuclear cascade of EAS. We neglect the angle between the trajectories of the pion and muon. It allows us to consider the pion as a muon, and assume that the point of birth of the muon is located on the axis of EAS. Also, we neglect the deviation of the muon in the geomagnetic field and consider the muon trajectory as a straight line.

Let muons and Vavilov-Cherenkov photons are born in point A at a depth of 300 g/cm^2 of the atmosphere along the shower axis (figure 3). On the way AB muons and photons pass Q = 1700 g/cm^2 of the atmosphere. By formula (1) we have the muons come to a point B at 14 ns earlier than photons.

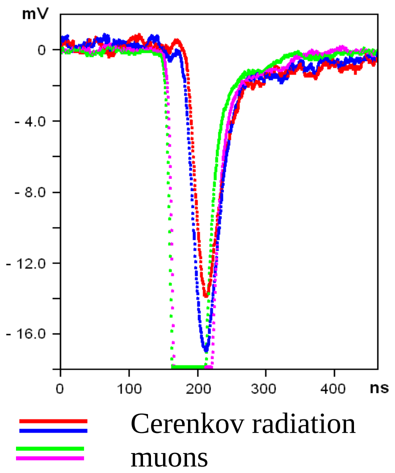

Figure 2. Experimental event 1.6.11.

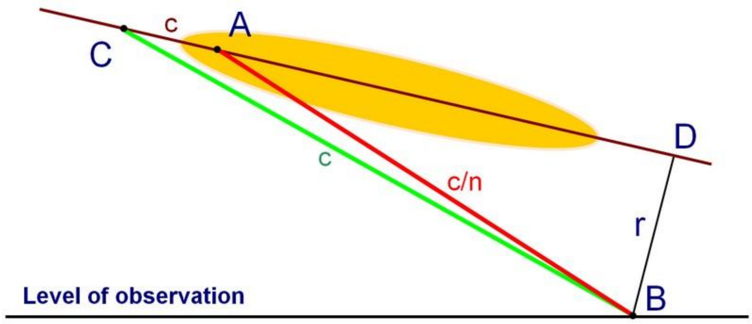

Figure 3. Geometry of muons and Cherenkov trajectories.

Muons which are ahead of the Vavilov-Cherenkov photons for more than 14 ns are produced before the photons. We consider a muon, which was born at C, and passing the way CB with the velocity c reached the detector located at point B. Let from point C simultaneously with muon comes out a particle passing the way CA with a speed c and emits Cherenkov photon at point A. This photon, passing the way AB with the speed c/n, is registered by the optical system, located at the point B.

A simple geometrical consideration of the triangle ABD and triangle CBD shows that, due to the difference of paths CB and $(CA + AB)$ and different speeds along the lines CB, CA and AB muon is coming to the point B before the photon by 20 ns, if the distance r between the shower axis and point B is equal to 300 m.

In the event shown in figure 2 muons come to point *B* before the Cherenkov photons at 27 ns, and were recorded simultaneously by two adjacent SC-detectors. Leading time 27 ns is possible only if the detectors are at a distance 400 m from the shower axis. Simultaneous recording of two muons by SC detectors means the density of the muon flux at a distance of 400 m from the shower axis was at least one muon per square meter.

Simulation of EAS with primary energy $E_0 = 10^{17}$ eV showed the density of one muon per square meter at a distance of 400 m from the shower axis is almost impossible, if the primary particle is a proton, alpha particle or nucleus of CNO group. Consequently, the considered EAS is caused by a heavier particle than the group of nuclei CNO.

4. Conclusion

1. HORIZON-T has been created and put into an ongoing operation.
2. First results show high information content for lateral-time characteristics of the individual strongly inclined showers.
3. EAS events have been detected at zenith angles 65-75 degrees, some of them had muon fluxes being ahead of Vavilov – Cherenkov ones by more than 20 ns.
4. It is shown that these showers are generated with high probability by rather heavy primary nuclei.

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