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Wide-angle telescope for registration of Cerenkov light reflected by snow surface [Ice Lake-p.Mussala]

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Abstract. An experiment using Cerenkov light of EAS, reflected from the snow surface of Ice Lake-p.Mussala, Bulgaria is described. They are presented some preliminary estimations of the energy threshold, expected pulse shape, and counting rate. The response of the telescope is carefully studied using MC modeling.

1. Introduction

The Cerenkov light from EAS reflected by snow surface gives the possibility for experimental investigation of the primary spectrum of cosmic ray with ultra high energies especially around the knee.

The Basic Ecological Observatory on peak of Mussala provides a real opportunity for realization of the method that was suggested by A.E.Chudakov (1972) [1]
The Ice Lake is located in the Mussala circus region, at 200 m below the peak of Mussala (2925-m a.s.l). The lake's area is approximately 20.10^3 m^2. Its surface retains an ice-cover approximately 7 to 8 months annually.

The construction of the telescope was started in autumn 2000.

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2.Detectors

The registration setting is positioned at 225 meters above the lake /2700m/ on the mountain ledge nearby. Two parabolic reflectors with 1-meter-diameter each, observe the Ice Lake. So its center is viewed under angle ~48^o.The light spot are detected by two photomultipliers (FEU-110) placed on the focal plane of the each reflector. The experimental setting up is shown on Fig.1.

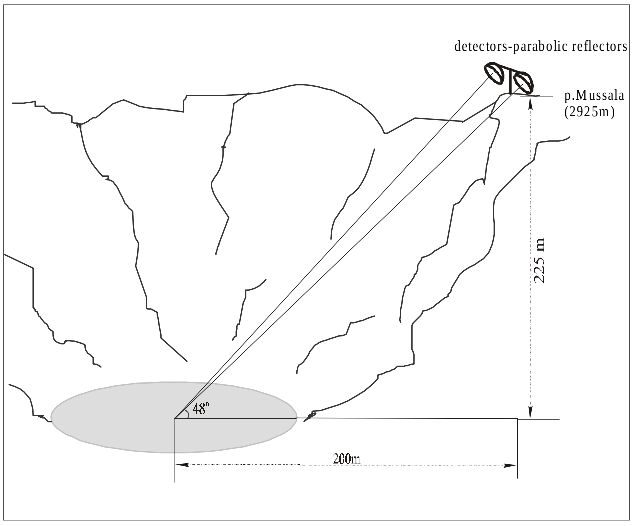

Fig.1: Scheme of the experiment

2.1.Estimation of the number of noise photons which reach The detector.

The light intensity of the night sky is taken according [2]

$I_{star.} = 1,3.10^{8}\ ph.cm^{-2}.s^{-1}.sr^{-1}$.

The number of background photons reached lake's surface for $1s/1m^2$ is:

$I = 1.8995x10^{12} ph.m^{-2}s^{-1}sr^{-1}$

The zenith angle for the photon flux, reflected by the surface, is limited by the terrain's specifics: d=0.73 rad

The next table indicates the star light background and its fluctuations in different time intervals.

Table 1

τ(s)	**number of photons**	**3σ**
30.10^{-9}	$1,155.10^{3}$	$1,0197.10^{2}$
150.10^{-9}	$5,777.10^{3}$	$2,2802.10^{2}$
300.10^{-9}	$1,1554.10^{4}$	$3,2247.10^{2}$
1	$3,8514.10^{10}$	$588,75.\ 10^{3}$

The expected Cerenkov photon flux is calculated on the basis of the model function [4] with the simplifying supposition about a constant flux density from the shower's axis up to 80 meters distance.
The calculations results are shown on Table 2.

Table 2

E,eV	**ρ,ph/m²**	**number of photons**
10^{12}	10^{2}	2.027
10^{13}	10^{3}	20.275
10^{14}	10^{4}	$2.027.10^{2}$
10^{15}	10^{5}	$2.027.10^{3}$
10^{16}	10^{6}	$2.027.10^{4}$

Bearing in mind the registration's requirement $N_{cer} > 3\sigma$, i.e. that the Cerenkov's pulse should exceed at least 3 times the star light fluctuations, the threshold energy of registered events is estimated about 10^{14}eV for 150 ns integration time of the detector.
/The noise estimate does not take into account the quantum efficiency of the photo-cathode; which is supposed 100%/

2.2.Estimation of a shape of the reflected Cerenkov light pulse.

In order to simplify estimation the pulse's shape, it is generally supposed that the front of Cerenkov light is: 1) flat; 2) vertical, and 3) all Cerenkov photons arrived simultaneously upon each point of the lake's area.

The time difference $\Delta\tau = \tau_2 - \tau_1$ between the appearance of a photon, respectively, from the closest and the furthest lake's points facing the detector, is approximately 500ns. ($\tau_1 = 776,7.10^{-9}$s; $\tau_2 = 1196,7.10^{-9}$s)
The pulse's shape is estimated for a shower, initiated by primary particle with energy 10^{14} eV whose axis falls onto the lake's center.
The lateral distribution of Cerenkov signal upon the surface area is calculated with the help of function

$$Q(r,E) = \frac{1}{A(E) + B(E)\cdot r + C(E)\cdot r^3} \qquad (2)$$

This function is derived by approximation on the calculation curves by P. Arqueros [5] for primary photons of energy range 10TeV-10PeV.
The number of photons N reflected by and arrived from elementary area ds is:

$$N = k \cdot Q(r,E) \cdot ds \cdot S_{\det} \cdot G \qquad (3)$$

Where k is coefficient of reflection for ice [3]; S_{det} is the area of the reflectors; G is geometric factor.
As well the time τ for a photon appearance from elementary area ds in the detector is estimated.
The correlation N (τ) is shown on Fig.2.

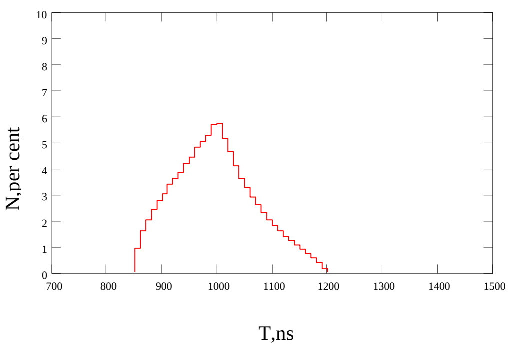

Fig.2: *The pulse shape estimated for a shower initiated by primary particle with energy 10^{14}eV whose axis falls into the lake's center*

T=0 corresponds to the moment of arrival EAS front to the reflecting surface.
The performed estimate of the signal /noise ratio (number of photons) for energy 10^{13}eV, 10^{14}eV, 10^{15}eV, 10^{16}eV for a central event for a resolution time above 150 ns, 300ns, 500ns is shown on Table 3.

Table 3

E, eV	**Number of photons by the overall reflecting surface**	**signal/noise ratio (number of photons)**		
		150ns	300ns	500ns
10^{13}	29.0355	0.13	0.09	0.06
10^{14}	494.207	2.06	1.53	1.19
10^{15}	$6.01107.10^{3}$	26.3	18.64	14.44
10^{16}	$8.06478.10^{4}$	353.68	250.08	193.7

3.Conclusion

Analyzing the signal/noise ratio (number of photons) one can show that the energy threshold of the registered events is above 10^{14}eV and the corresponding counting rate is expected about $150h^{-1}$.
Moreover, some experimental tests have been performed in order to verify the calculated pulse shapes using a storage oscilloscope.
It is obtained good agreement between the calculated and measured pulse shapes.

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