A search for astrophysical point sources of neutrino with high mountain SHALON mirror Cherenkov telescope

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***Abstract*— A neutrino telescope detects the Cherenkov radiation generated in water or ice by passage of relativistic charged particles produced by neutrino collisions with nucleons in the detector volume. Because of weakness of neutrino interaction the very large detector volume is required. Some alternative approaches have been proposed. One of them is using a earth matter or mountain as a target volume for conversion neutrinos to leptons which then initiate extensive air shower (EAS) in the atmosphere, then showers can be detected by Cherenkov telescope. Observations of neutrino initiated EAS at the mountain shadow seems attractive because of mountain valley screened from background showers of cosmic rays and the only particles that can survive are neutrinos with energies $> 10^{13}$ eV came under the horizon. The observation has been carried out since 1992 at high mountainous Tien -Shan station with SHALON Cherenkov mirror telescope with $\sim 11.2\ m^2$ mirror area and image matrix of 144 PMT with full angle $> 8^o$. The telescope characteristics permitted to start the search of local neutrino sources with energy $10^{13} - 10^{16}$ eV on EAS generating in mountain-range located at some 7.5 and more kilometers from gamma-telescope (in Russian the abbreviation SHALON means - the Extensive Air Showers from Neutrino). The analysis of results of observation of extensive air showers at height of 3338 m above the sea level by means of gamma-telescope SHALON at the zenith angles 72^o, 76^o, 84^o, 97^o are presented and compared with the data of detection of showers according to the direction into the zenith. The analysis of 324 hours of SHALON observation of Cherenkov bursts at angle of 97o results in 5 events from possible source that may be interpreted as EASs from neutrino interaction products.**

I. INTRODUCTION

The detection of Extraterrestrial Very High Energy Neutrinos by Atmospheric Cherenkov Telescopic System SHALON is discussed. The analysis of results of observation of extensive air showers at height of 3338 m above the sea level by means of gamma-telescope SHALON at the zenith angles $72°$, $76°$, $84°$, $97°$ are presented. The observation results are compared with the data of detection of showers according to the direction into the zenith. The observation has been carried out at Tien -Shan station with SHALON gamma-telescope (fig. 1). The SHALON telescopic system has mirror with

Fig. 1. Atmospheric Cherenkov Telescopic System SHALON

area of $11.2\ m^2$ and 144 PMT matrix with $< 0.1°$ angular resolution, that has the most in the world angular size - $> 8°$. It allows to control the background of cosmic ray particle emission and the atmospheric transparency continuously with observation that means the increasing of observation efficiency. So it is the telescope characteristics that permit to start the search of local neutrino sources with energy $10^{13} - 10^{16}$ eV on EAS generating in mountain-range located at some 6 and more kilometers from gamma-telescope (in Russian the SHALON abbreviation means - the Extensive Air Showers from Neutrino) [1], [2], [3], [4], [5]).

A neutrino telescope detects the Cherenkov radiation generated in water or ice by passage of relativistic charged particles produced by neutrino collisions with nucleons in the detector volume. Because of weakness of neutrino interaction the very large detector volume is required. Some alternative approaches have been proposed. One of them is using a earth matter or mountain as a target volume for conversion

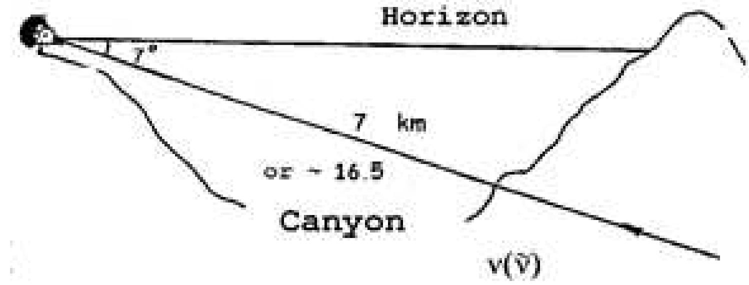

Fig. 2. The geometry of down horizontal observation sessions.

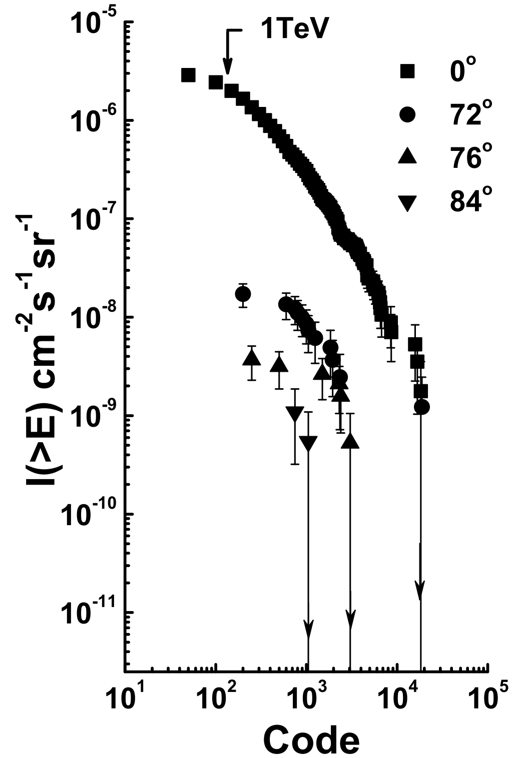

Fig. 3. The spectrum of extensive air showers Cherenkov radiation by telescope SHALON observation within 8° full angle. PMT amplitude arbitrary units are laid off along the abscissa.

TABLE I
THE ATMOSPHERE DEPTH AT DIFFERENT ZENITH ANGLES

Zenith angle, $\Theta°$	Atmosphere depth, g/cm^2	Number of Cherenkov burst per hour
72°	2250	7 ± 1.14
76°	3000	1.8 ± 0.5
84°	5950	0.5 ± 0.01

neutrinos to leptons which then initiate extensive air shower (EAS) in the atmosphere, then showers can be detected by Cherenkov telescope. Observations of neutrino initiated EAS at the mountain shadow seems attractive because of mountain valley screened from background showers of cosmic rays and the only particles that can survive are neutrinos with energies $> 10^{13}$ eV came under the horizon.

II. EXTENSIVE AIR SHOWERS UNDER A LARGE ZENITH ANGLE

The SHALON mirror telescope due to the trigger control of the detection of bursts of a short-range (8 nsec) signal in 4 PMTs of the light-receiver matrix allows one to know the number of observed bursts without observation of conditions of an angular picture of a Cherenkov burst. The telescope is calibrated according to the observations of EAS of cosmic ray

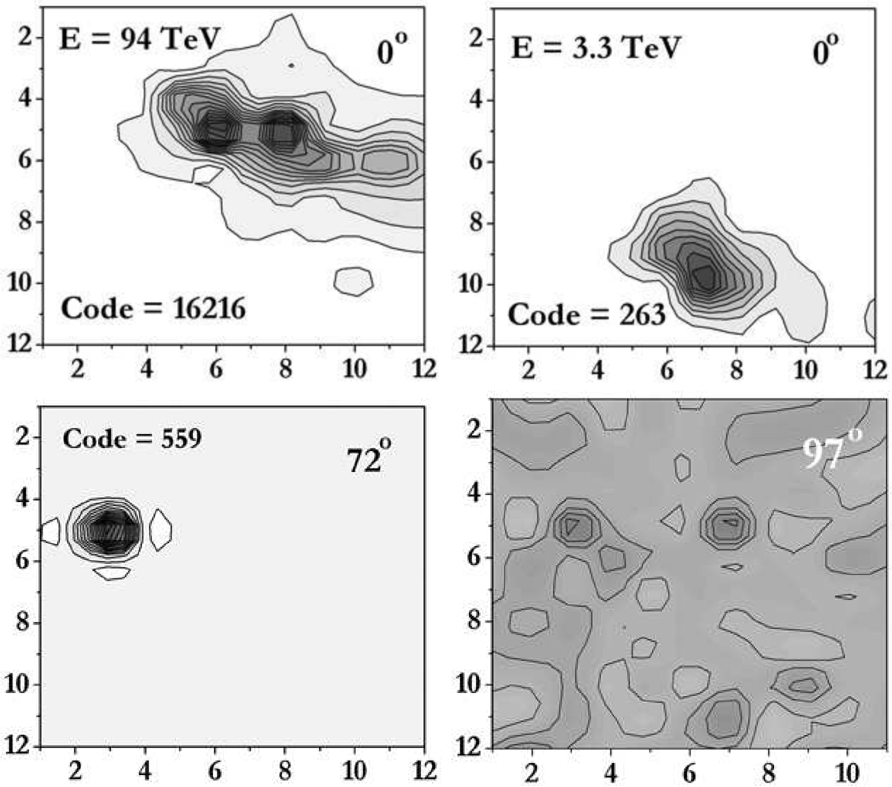

Fig. 4. The examples of showers recorded in PMT matrix at different zenith angles. The amplitude of gray - scale shower images is proportional to the ADC count. The number, named CODE shows the range of detected signals in the ADC counts, which are proportional to shower energy.

at $0°$ - zenith angle. The cosmic ray shower image detected in the SHALON telescope, generally is elliptic spot in the light receiver matrix, written in the ADC counts (CODE). Observations at large zenith angles have been aimed on study of spectra of the air showers induced by cosmic rays crossing through different atmosphere thickness and events accompanying the passing of EAS and cosmic ray particles near horizon. The observation at large zenith angles 72^o, 76^o, 84^o showed that the efficiency of Cherenkov light detection drops essentially as a zenith angle increases, perhaps because of dissipation and absorption in the atmosphere. So, the comparison of observation results shown that at the zenith angle $84°$ the number of observed showers is ~ 25 times less than expected by estimation with neglecting by absorption and dissipation of Cherenkov photons in the atmosphere (table I, fig. 3, 4).

The analysis of the observations allows one to make the following conclusion. At first, a night star sky doesn't produce any background events, preventing the observations of electron-photon cascades coming from under the earth surface. Secondary, the observation of Cherenkov bursts from extensive air showers under the large zenith angles, for example using of horizontal extensive air showers for investigation of an energy spectrum of ultra-high energy cosmic rays is complicated by absorption of Cherenkov photons by a large atmosphere thickness.

III. The observations of Cherenkov bursts under the 97^o zenith angle

SHALON Cherenkov mirror telescope is located at 3338 m a.s.l. The mountain range lies in the east direction and is more than 4300 m a.s.l. The mountain range is about 20 km long. The thickens of matter in the telescopic field of view is from 2000 to 800 kms; viewed mountain slope area is $> 7\times10^5\ m^2$.

For telescope located about 7kms away from the mountain slope horizontally, the shadow of mountain is about $7°$ in elevation. In actual conditions the mirror telescope placement the distance till the opposite slope of the gorge is ~ 7 km or ~ 16.5 radiation units of length, that is quite enough for the development of an electromagnetic cascade till the structure characteristic for the rarefied atmosphere. The purpose of observations was revealing of background conditions when anthropogenic sources of light are absent. During 324 hours of observations 5 events were detected (figs. 5 left) which have expected angular characteristics of a light burst of an electron-photon cascade developing within a telescope observation angle. These showers have energy in the range of about $6 - 17.5$ TeV. All other 318 events of detection of short-range light bursts in the atmosphere have not a narrow angle light direction and are chaotically distributed along the whole matrix or its part of a light-receiver (see figs. 4 for 97^o). These events may be interpreted as a reflection of a Cherenkov burst from a snow mountain slope or as an ionization luminescence

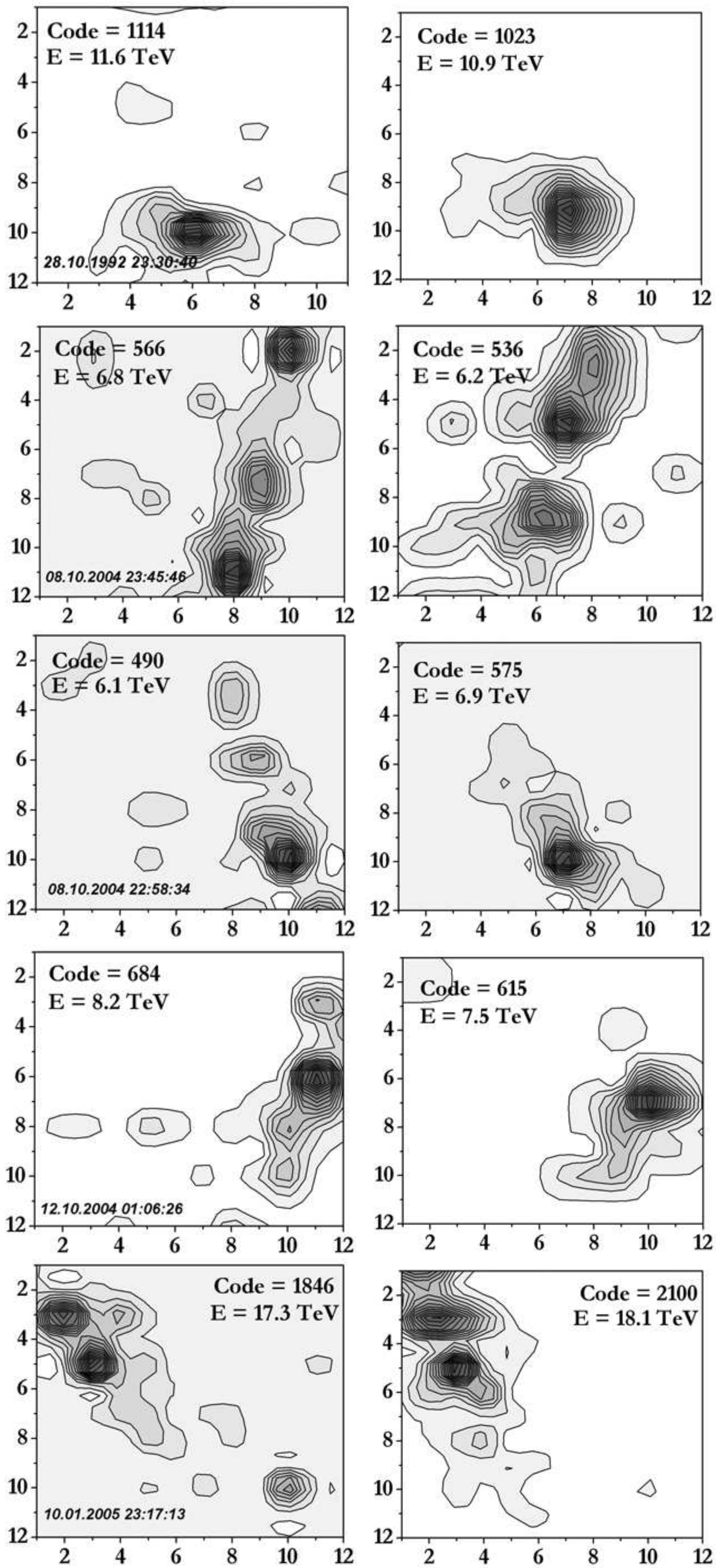

Fig. 5. **left** - Cherenkov Radiation of Extensive Air Showers Observed at 97° Zenith Angles by SHALON; **right** - Cherenkov Radiation of Extensive Air Showers Observed at 0° Zenith Angles by SHALON.

of the atmosphere while an extensive air showers transition within a telescope observation angle.

IV. Metagalactic and galactic sources of very high-energy gamma-quanta and neutrinos with the mirror Cherenkov telescope SHALON

Observations at 97° zenith angle have been done in cloudless nights in absence of artificial lights and dry air. During 324 hours of observation 323 short-range bursts were recorded. The picture of 318 of these is flash that chaotically or smoothly spread along whole the matrix or its part (see figs. 4 for 97^o). These events may be interpreted as a reflection of EAS Cherenkov burst from a snow mountain slope or as a ionization luminescence of the atmosphere if vertical EAS transits within field of view. But 5 events (figs. 5 left) have form characteristics similar to those observed at 0° zenith angle (figs. 5 right). These cascades look like the usual extensive air showers generated in atmosphere with narrow light shape. The shower energies are in the range of 6 - 17.5 TeV (figs. 5 left). The background for this events can be some reflections of cosmic ray EAS in the mountain slope. First of all it could be a reflection of showers initiated by particles born in interaction of very high energy cosmic rays and rock matter nucleons. The energy of detected showers is more than 6 TeV. There is no albedo particles of such high energies. One more source of particles with high transverse energy is jet production. The probability of hadronic jet production with energy of observed showers is ten orders of magnitude less than one for detection of shower generated by secondary particles of UHE neutrino interaction. The estimated neutrino event rate is one shower per 100 hours for neutrino of all flavors and fluxes expected by models. It corresponds to rate of $\sim 10^{-15}\ cm^{-2}s^{-1}$ that is comparable to fluxes of weak gamma-quantum sources presently observed by SHALON.

V. Conclusion

It is supposed to overcome the main difficulty of observation of EAS, generated by neutrino in conditions of high mountainous observations, connected with the small cross section of neutrino-nuclei inelastic collisions. Two facts allow to carry out the search experiments. The hadron cascades with energy $> 10^{13}$ eV are generated by neutrino in the ground of mountain on the thickness $< \ 300\ g/cm^2$. The Cherenkov radiation of the hadron cascades will be observed along the direction of neutrino by gamma-telescope placed on the distance about 7 kms from a mountain slope in area of more than $> 7 \times 10^5\ m^2$. These cascades look like the usual extensive air showers generated in atmosphere with narrow light shape. Presently, the fluxes of galactic gamma-quantum sources Cygnus X-3, Tycho's SNR, Geminga of $< 10^{-14}\ cm^{-2}s^{-1}$ are observed by SHALON. The appearing of one shower per > 100 observation hours is expected if the flux of neutrino from local sources is $10^{-15}\ cm^{-2}s^{-1}$ [6 – 13] During 324 hours of observations 5 events (figs. 5 left) were detected which have expected angular characteristics of a light burst of an electron-photon cascade developing within a telescope observation angle.

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