ON A LARGE-SCALE RADIO CHERENKOV OBSERVATORY

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Se propune construcţia unui telescop de neutrini într-o mină de sare, detecţia fiind bazată pe efectul Cerenkov. Sunt prezentate structura detectorului şi evoluţia semnalele radio de la producere, până la antena de detecţie. De asemenea, am descris şi limitările introduse de raportul semnal zgomot şi volumul efectiv echivalent.

We propose the construction of a neutrino large-scale radio Cherenkov observatory in salt mines. The basic structure of the detector is described and the characteristics of the radio signal are analyzed, on its propagation from the site of the shower to a point where it intersects the antenna. Signal-to-noise ratio (SNR) and effective volume limiting situations are also presented.

Keywords: Neutrino detection, salt, UHE cosmic neutrinos

1. Introduction

Several neutrino detectors were developed and built recently in the Arctic ice or in seawater [1]. We propose the construction for the first time of a radio Cherenkov neutrino observatory in a Romanian salt mine. The main goal of the construction of a large volume, ultra high energy (UHE) neutrino telescopes is the detection of extra-Galactic neutrino sources [2]. This can be done because UHE cosmic neutrinos, stable neutral particles, can travel unreflected by magnetic fields but unlike photons (that are easily stopped by matter) they interact very weakly. Due to that, neutrinos can reach ground level detectors directly from their sources.

G. A. Askaryan suggested in [3] that a nanosecond pulses of coherent Cherenkov radio emission could be observed in directions corresponding to a ‘‘spread’’ conical surface with the opening equal to Cherenkov angle [4]. For photons with wavelengths longer than the transverse dimensions of the cascade, like radio frequency (RF) photons, the

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radiation is coherent and the electric held is proportional to the negative charge in the cascade [5].

2. Effective volume

As presented in [6], we decided to select the operating frequency of 187.5 MHz and to keep the distance between antennas around 2 m in order to avoid mutual coupling.

We will consider the parameterization of the coherent radio pulses from showers presented in [7] for frequencies typically below 10 GHz.

The coherent RF waves will propagation in salt, so according to [5] we can expect no scattering effects and depolarization phenomena. As propagation effects we will consider only absorptions in the dielectric medium and reflexions at separation borders.

As we have no experimental measurements yet, we will assume a homogeneous, nondispersive media characterized by a dielectric constant of $\varepsilon_1 = 6 + 0.001j$. Note that the imaginary part of the permittivity is a measure of the absorptions in the medium.

The power delivered to the receiver is maximum if the antenna (considered to be a dipole and modeled according to [6]) is followed by a matched filter with a matched load impedance. This gives an expression for the voltage delivered to the load, V_L. One can see in figure 1 that the voltage drops almost exponentially with the distance R between the shower and antenna. As expected from the transfer function of the dipole antenna, the maximum voltage is recorded for waves coming at an angle of $90\,\text{deg}$. An increase in the energy of the primary particle with a factor of 100 is producing a voltage that is one order of magnitude higher.

We investigate the problem of the possibility of measuring the signal under noise. Detection of known signal in a white Gaussian noise background is a standard problem of signal processing and is maximized in the sense of maximizing the signal to noise ratio by use of a matched correlation receiver [8]. We have assumed in our calculations a system temperature of 450K (based on about 310K for salt and a receiver noise temperature of 140K, consistent with low-noise amplifiers available commercially).

The SNR depends on more than one factors but the most important is the energy of the primary particle. Therefore, an imposed SNR will give the minimum (threshold) energy that can be detected. Other factors to be included when considering the threshold energy are the distance between shower and antenna and the angle of incidence with respect to the normal (broadside) of the antenna. At an imposed SNR of 5, observations made

100m from the shower at an angle of 60 deg. require a particle with a minimum energy of 231 x10^{15}eV. In the case of a lower SNR (e.g. 1), the threshold energy is 109x10^{15}eV.

The collection of potential shower positions that satisfies a signal to noise ratio greater than a given value defines an effective volume for events with energies of primaries E_0 and incident direction $\theta=\theta_C$. At energies of 10^{18}eV, the region that can be resolved by each antenna extends to more than 1 km away from the antenna. The volume that one antenna can sense reaches tens of cubic kilometers at the highest energies (fig. 2). This effect of the overall very large, km-scale detection volume will compensate for the small neutrino cross sections and the small expected fluxes of high-energy cosmic neutrinos.

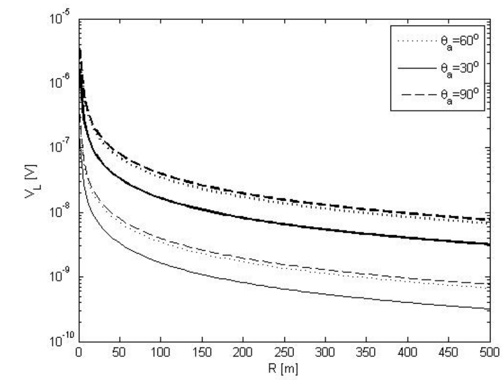

Fig. 1. The voltage delivered to the receiver versus the distance between antenna and the shower for a primary particle energy of 10^{16}eV (thinner lines) and 10^{18}eV (thicker lines) for three incoming angles: 30° (continuous lines), 60° (dotted lines) and 90° (dashed lines)

3. Conclusions

In this paper we calculated the geometrical characteristics of the detector and we analyzed the characteristics of the radio signal by including for the first time propagation effects. Compared to [8], the minimum energy that can be detected is given by the imposed value of the signal to noise ratio. We concluded that only particles with energies higher than 10^{17}eV can be observed. This threshold energy has been chosen as a limit for detection at distances of more than 100m away from the shower development, in any possible configuration of the arrival direction of the UHE neutrino. Our main conclusion is that in order to probe a ~1km^3 volume is enough to have just a few receivers operating at 187.5MHz. This number indicates that unprecedented target masses for ultra high energy neutrinos are feasible using radio as detection mechanism.

This radio technique comes to compensate the optical methods, limited by the neutrino flux and detector efficiency at about 10^{14}eV.

By observing in the RF spectrum we can maximize the number of detected Cherenkov photons produced by energetic charged particles while keeping the density of antennas (and thus the cost of the experiment) low.

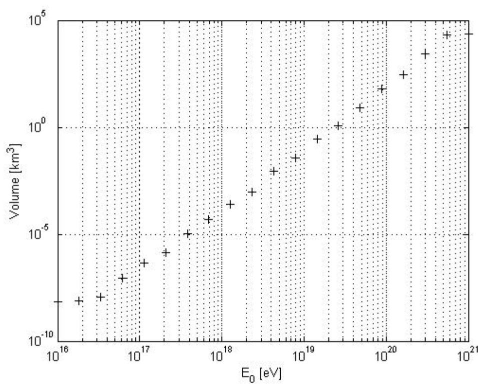

Fig. 2. Total volume that each antenna can observe versus the energy of the primary particle

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R E F E R E N C E S

[1] *I. Kravchenko* et al., “Limits on the ultra-high energy electron neutrino flux from the RICE experiment”, Astropart. Phys. 20, **195** (2003)

[2] *Eli Waxman*, “Extra galactic sources of high energy neutrinos”, arXiv:astro-ph/0502159v1

[3] *G.A. Askaryan*, “Excess negative charge of electron-photon shower and the coherent radiation originating from it”, Sov. Phys. JETP 14, **441** (1962)

showers in different media: A unified parameterization”, Phys. Rev. D, **74** (2006)

[4] *E. Zas, F.Halzen, T.Stanev,* “Electromagnetic pulses from high energy showers: Implications for neutrino detection”, Phys. Rev. D 45, **362** (1992)

[5] *H. Landsman, L. Ruckman, G. S. Varner,* “AURA—A radio frequency extension to IceCube”, Proceedings of the 30th International Cosmic Ray Conference, **Vol. 4** (HE p.)

[6] *A. Badescu et al.*, 2010, “Radio technique for investigating high energy cosmic neutrinos”, to appear in Romanian Reports in Physics

[7] *P. W. Gorham, D. Saltzberg, R. C. Field, E. Guillian, R. Milincic, D. Walz, D. Williams,* “Measurements of Coherent Cherenkov Radiation in Rock Salt: Implications for GZK Neutrino Underground Detector”, Phys.Rev. D72 (2005) 023002

[8] *P.W. Gorham, D. Satzberg, A. Odian, D. Williams, D. Besson, G. Frichter, S. Tantawi,*” Measurements of the suitability of large rock salt formations for radio detection of high-energy neutrinos”, Nucl. Instrum. Meth. A **490** (2002)