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Deposited Energy Distribution in the Giant Showers in Water

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Abstract

Recently some new showers with energies above 10^{20} eV were detected. In a model with the topological defects neutrinos should dominate in the primary spectrum at energies above this threshold. In interactions with nuclei a large fraction of a neutrino energy may be deposited to electron. As the cross section of such interactions is small, only the ocean may be used as a possible detector volume with dimensions of 100×100 km^2 or even more. Due to the Landau-Pomeranchuk-Migdal effect the fluctuations in the development of the electron-photon showers in water play an important role. Comparison of the average shower with the real individual cascade showed that the signal from such showers should be estimated only for the individual cascades. Thus some distributions of deposited energy in showers were calculated to estimate decreasing of possible signal relative to the Bethe-Heitler showers.

1 Introduction:

The giant air showers so far detected have the highest energies of $(2 \div 3) \cdot 10^{11}$ GeV (e.g. see Hayashida et al., 1994, Bird et al., 1995, Antonov et al., 1999). The origin of the primary cosmic ray particles with such huge energies is to be discovered. As it was shown by Greisen (1966) and Zatsepin and Kuzmin (1966) the primary protons suffer the large energy loss due to pion photoproduction on the microwave background if their energy is well above the threshold of $2 \cdot 10^{10}$ GeV. Thus these protons can reach the Earth from the distances not larger than about $20 \div 30$ Mpc. The possible sources of these primary protons may be observed if the standard acceleration is suggested. The decay of the possible topological defects may provide an alternative origin of the primary particles with such huge energies. Though the scenarios with the topological defects developed by Hill (1983), Aharonian, Bhattacharjee and Schramm (1992) and Gill and Kibble (1994) meet some problems they have a very unique feature. As a result of top-down cascading the large flux a neutrinos are especially produced. The particular scenario suggested by Protheroe and Stanev (1996) predicts at the energy of 10^{12} GeV the neutrino flux, which is approximately two order of magnitude higher than the proton flux. So one neutrino with the energy of 10^{12} GeV is expected to reach the Earth within the area of 100 km^2 per year. The neutrino-nucleon cross section estimated by Butkevich et al. (1995), Frichter, Mc Kay and Ralston (1995), Gandhi et al. (1996) and Parente and Zas (1997) has a value of 10^{-31} cm^2 at 10^{12} GeV. So the mean free path for interaction is equal to 10^4 kg/cm^2 or the depth of 100 km of water. So the possible detector to catch these neutrinos should approximately have the area of 100×100 km^2 in deep ocean to register about 10 nearly vertical cascades induced by neutrinos per year. The first point to be highlighted is parameters of such cascades.

2 The LPM Effect:

If the electron neutrino transfers most of its energy to an electron then the electron-photon cascade starts to develop in water. Landau and Pomeranchuk (1953) find out that the cross sections for the bremsstrahlung and pair creation would decrease considerably with the growing energy (the LPM effect). Estimations of these cross sections by Migdal (1956) showed a drop which is proportional to $E^{-0.5}$ in high energy limit.

Some peculiarities of the electron-photon cascades with the LPM effect taken into account were discovered by Konishi, Misaki and Fujimaki (1978) and lately by Dedenko et al. (1981), Mc Breen and Lambert (1981), Stanev et al. (1982), Misaki (1990), Konishi et al. (1991) and Konishi and Misaki (1997). For example the cascade length should approximately increase ~ 100 times in water at the energy of 10^{12} GeV. Fluctuations in the cascade development would be very large. Some preliminary estimation of fluctuations is main goal of this calculation.

3 Results and Discussion:

Fig.1 displays how the individual energy deposition may differ from the mean curve in 20 points separated by 5000 g/cm^2. It should be emphasized that no smooth curves are suggested to link these points because no strong correlation is expected. The total statistics of 100 events may not be enough to show the mean curve unambiguously. But the main result is the considerable fluctuations in the individual energy deposition. Fig.2 illustrates some plausible ratios of the standard deviation σ to the average values E of the energy deposition. The rate of the energy deposition may considerably vary at different points. Thus the energy estimation of the individual cascade in water is a very difficult problem. At last Fig.3 demonstrates the distributions of the energy deposition at 3 levels of 25, 45 and 65 kg/cm^2 of the longitudinal cascade development. The maximum of the energy deposition in case of Bethe-Heitler showers is $1.5 \cdot 10^9$ GeV/(g/cm^2).

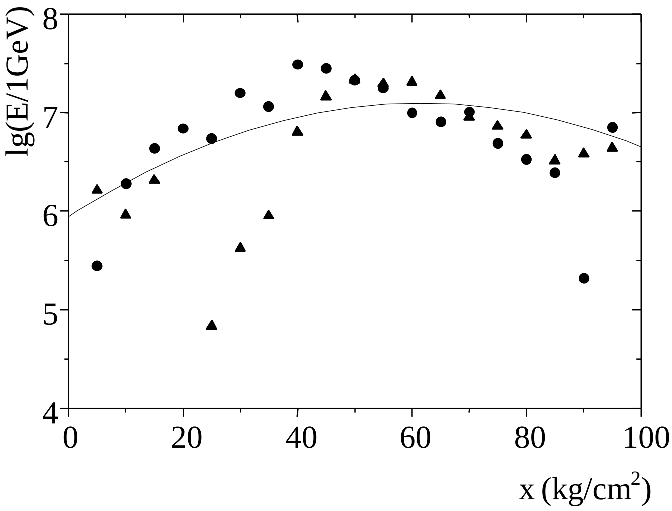

Figure 1: The mean energy deposition and 2 individual curves

As for these 3 levels the calculated maximal values of the energy depositions are equal to $2.3 \cdot 10^7$ GeV/(g/cm^2), $3.1 \cdot 10^7$ GeV/(g/cm^2) and $3.4 \cdot 10^7$ GeV/(g/cm^2) accordingly.

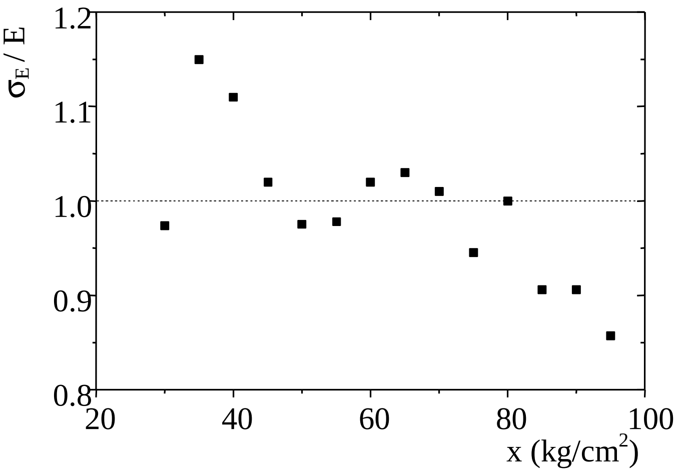

Figure 2: The relative standard of the energy deposition

Thus the energy deposited in cascades induced by the electron with the energy of 10^{12} GeV and calculated with the LPM effect taken into account is approximately ~100 times less than for the Bethe-Henitler showers but instead the length of cascade is ~100 times larger. Fluctuations in the individual cascade development are very high. Thus any signal should be estimated only for the individual shower.

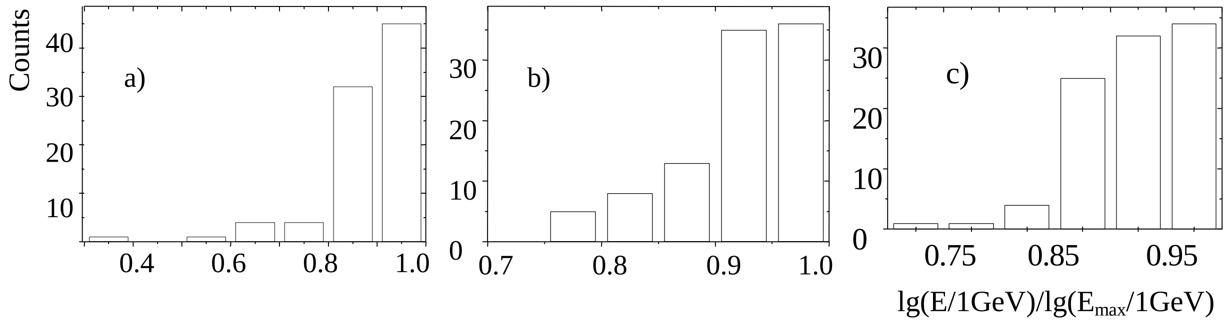

Figure 3: Energy deposition distributions. a) 25 kg/cm^2, E_{max}=2.3·10^7 GeV/(g/cm^2), b) 45 kg/cm^2, E_{max}=3.1·10^7 GeV/(g/cm^2), c) 65 kg/cm^2, E_{max}=3.4·10^7 GeV/(g/cm^2).

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