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Lepton fluxes in underground salt dome

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Ultrahigh-energy neutrino originated from the GZK effect is the most plausible source for high energy neutrinos. However, their small flux and low interaction probability make their detection very challenging. To have a proper event rate, the interaction volume must be much larger than the km^3-size detector currently under construction. One of the alternative techniques resorts to the detection of coherent radio waves produced inside an underground salt dome. We have developed a Monte-Carlo simulation code for the interactions and propagations of leptons inside the Earth. In this code, the Earth is treated as a three-layer sphere consisting of iron in the core, standard rock in the mantle and water on the surface. We have also added salt as the fourth material surrounding the detector. The energy loss of muons and tau leptons in salt are calculated. To simulate a 100-km^3 water-equivalent target volume, we employ a spherical sphere salt dome of 5 km in radius. The lepton fluxes from neutrinos of three flavors will be reported in this conference.

1. Introduction

Ultra-high energy cosmic rays have been observed since the 1960s. The existence or absence of GZK cutoff has been a major debate between two experimental groups, AGASA and HiRes, in the last decades. With or without GZK cutoff, the byproducts of $p + \gamma_{\mathrm{CMB}}$ interaction will always produce ultrahigh-energy neutrinos (> EeV) (UHE-ν). This is the most certain source of high-energy neutrinos and neutrino telescopes are constructed for their detections. However, the GZK-neutrino flux is too weak for detectors of km^3 water-equivalent size, such as IceCube[1] or KM3NeT[2] to detect. To have a reasonable event rate of 1 event/year, an acceptance in the order of 100 km^2 sr is required [3]. Owing to the high construction cost, it is not feasible to install a PMT-based detector in such a large volume.

Alternative approaches have been proposed. One is the extension of the air shower experiments utilizing the Earth-skimming neutrinos. Showers initiated by decay of tau leptons, which are produced by charged current interaction inside the Earth. Showers can be detected by Cherenkov[4] and/or fluorescence [5] light detector similar to HiRes. A major breakthrough in shower detection technology is the radio detection by Askaryan effect [6], which provides a new method for detecting UHE-ν. Some preliminary studies (ANITA, Gold-stone, RICE [7]) are currently conducted. The cost of building a radio array in underground neutrino telescope is greatly reduced, which make it more attractive for Mega-ton detector. A possible site for such an experiment is an underground salt dome, which provides better transparency to radio wave than ice. When designing a detector, the main issue is to understand how much volume is needed in order to have a proper event rate. Many similar studies were conducted with detectors installed in ice or water. In this study, we examine the leptons fluxes in an underground salt dome.

2. Simulation

Assuming full oscillation, three flavors of UHE-ν of three flavors are injected to the Earth at a 1:1:1 ratio. Interactions between neutrinos and leptons were simulated with a Monte-Carlo program [8]. The charged and neutral current interactions take place inside the Earth, which is modeled with density and composition varying with geocentric distance. Lepton propagates with energy loss and/or decay/interaction. The UHE-ν fluxes [9] entered the Earth isotropically.

Since detector array may detect events out side array, we define a Detector Sensitive Region (DSR). In this simulation, DSR is a sphere of radius 5 km and the center of sphere is at 6 km below mean sea level. Salt rock filled the DSR, while standard rock filled the exterior of DSR. So, the top of DSR is buried under 1 km of rock. The energy loss and range of tau-lepton in salt is calculate with mean A=29.2447, mean Z=13.5 , and density= 2.16532g/cm^3.

3. Results

We inject 10^6 events of tau-neutrinos to DSR. The energy of each event is sampled from GZK differential flux from 10^5 GeV to 10^{10} GeV. This number corresponds to 97.8 years of full-time operation. In total, 6251 tau-leptons arrived in DSR. The event rate is approximately 0.032 event/(km^2 sr yr).

When leptons enter DSR, we record their positions, directions, and related information for each interaction. The energy and cosine of zenith angle of tau-leptons entering DSR are shown in Figure 1. The energy spectrum and arrival directions are shown in Figure 2 and Figure 3 respectively.

Most of these events (~87%) are down-going events with cosθ > 0. Although up-going events are fewer, (~13% of all events), they are not totally vanish due to regeneration process ($\nu_\tau \rightarrow \tau \rightarrow \nu_\tau$). Fewer events (~0.36%) pass through the core of the Earth, where density is highest and range of tau-lepton is shorter by 60% othan that in the standard rock. For those down-going events, their spectra are similar and concentrate in between 108 GeV to 109 GeV, while the up-going events mostly fall below 108 GeV, except some Earth-skimming events.

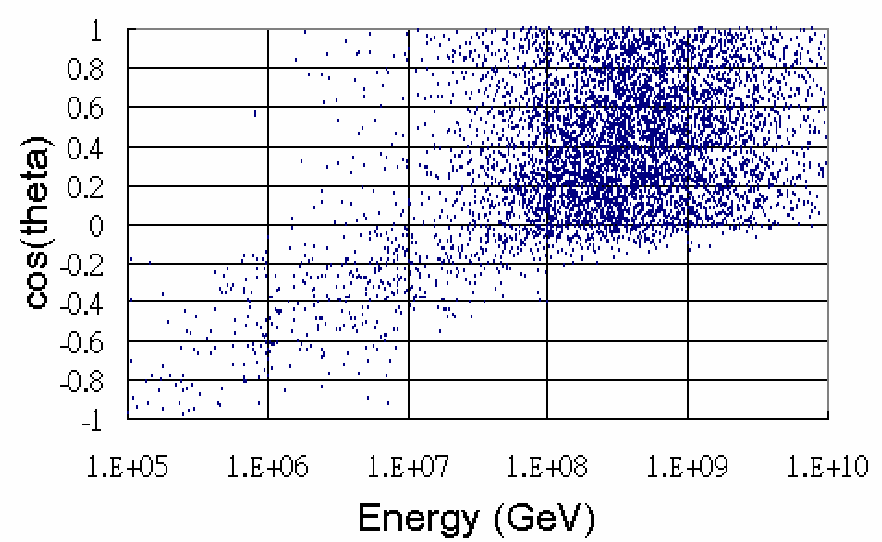

Figure 1. The energy and cosθ distribution for tau-leptons arrive in the simulated salt dome. Y axis, cosθ, is cosine of zenith angle of event arrival direction. Events coming from zenith have cosθ = +1. Up-going events have cosθ < 0. Events pass through the core of the Earth have cosθ < -0.83. X axis is tau-lepton energy when entering the salt dome.

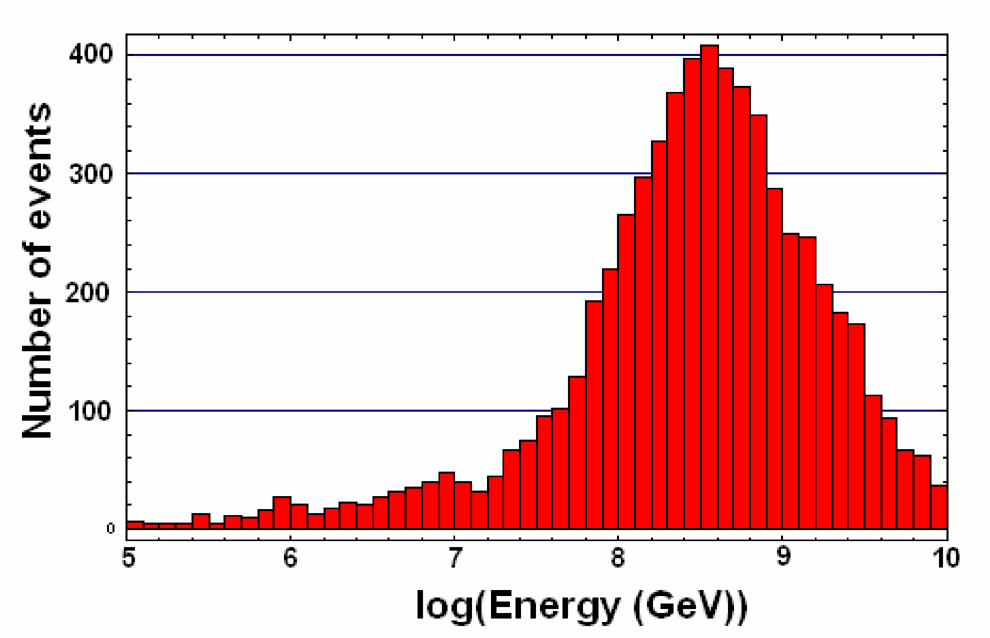

Figure 2. Energy distribution of tau-lepton entering slat dome.

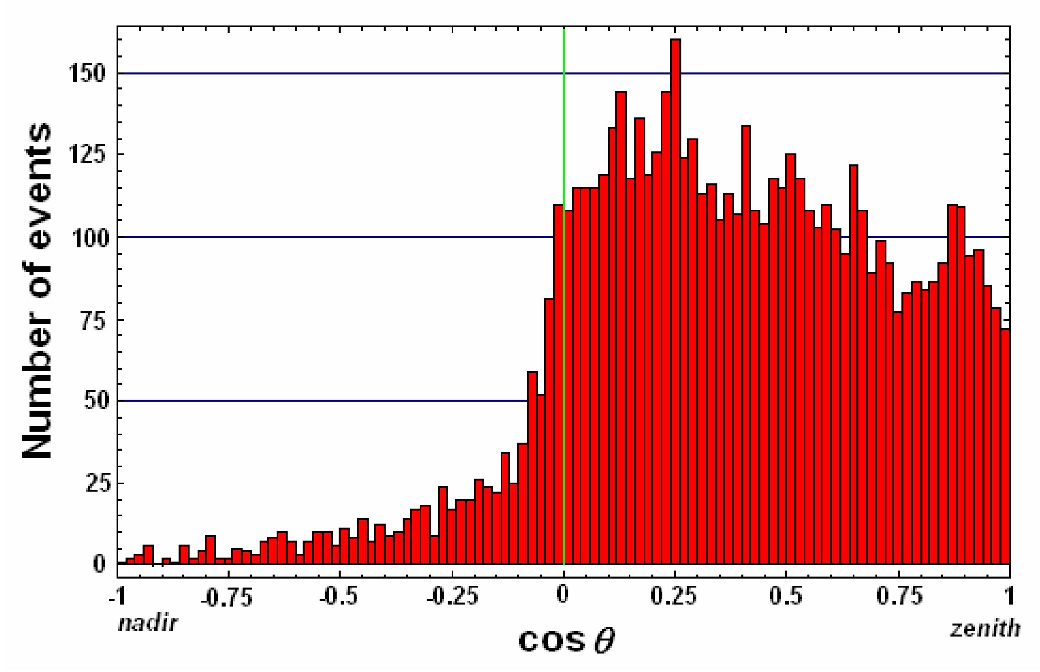

Figure 3. Angular distribution of tau-leptons entering the salt dome.

4. Conclusions

We study the tau leptons flux in an underground salt dome. 10^6 tau neutrinos are injected to a sphere of 5 km radius bury under 1 km of rock. 6251 tau-leptons are produced inside this sphere. The equivalent operation time is 97.8 years and the event rate is approximately 0.032 event/(km^2 sr yr).

Based on the energy distribution in Figure2, the energy sensitive range of SalSA should be above 10^8 GeV. However, the range of tau-lepton is 3.4 km to 11 km [8] in this energy range. Most of these events would not produce the double bang signature of tau-leptons. It is necessary to low energy threshold to 3×10^7 GeV, where tau-lepton range drop down to 1 km.

Based on the event arrival direction distribution in Figure 3, most of events come from zenith angle 60° to 90°. Detector array should be positioned at orientation most sensitive to these angles. The best shape of salt dome be longer in horizontal direction than vertical direction. Longer horizontal distance provides better chance for detection of double-bang events.

4. Acknowledgements

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