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# Simulation of Horizontal Extensive Air Shower

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**Abstract:** Earth-skimming neutrino experiment such as NuTel or CRTNT detects air shower, which is produced by decay of tau lepton, from near horizontal direction. Traditional shower simulations have difficulty in simulating shower at zenith angle near 90 degree, where some variables diverge to infinity. Recent CORSIKA simulation code had updates on simulation of horizontal air shower. We also developed a method to simulate horizontal air shower. This talk will compare results from both methods.

## Introduction

Neutrinos play important roles in many astrophysical processes, starting from MeV neutrinos from fusion inside stars and supernova explosion, PeV neutrinos from active galactic nuclei, and even EeV cosmological neutrinos from GZK interaction of ultrahigh energy cosmic rays with CMB photons. Although neutrinos interact in weak interactions only, their interaction cross-section is approximately proportional to $E^{1.4}$ at energy $E >$ PeV ($10^{15}$ eV) [1]. This feature makes interaction length shorter than the diameter of the Earth. The Earth starts to be opaque to neutrinos.

High energy neutrinos interact with materials in the Earth through charged current or neutral current interaction. Neutral current interaction is inelastic collision with nuclei and the shattered nuclei can be detected as a hadronic shower inside a underground detector. Charged current interaction produce leptons, which then can be detected by underground detectors. Conventional neutrinos detectors must be buried under heavy protection against contamination of atmospheric muon. One of the main difficulties of these detector is identify neutrino flavors. There are ambiguities between $\nu_e$ and $\nu_\tau$ at $E < 1$ PeV (both behave like a shower) and between $\nu_\tau$ and $\nu_\mu$ at $E > 20$ PeV (both behave like a trak).

At enrgy higher than 1 PeV, Earth-skimming neutrino telescopes provide a new approach for detecting $\nu_\tau$ events. Detection of such events proves not only the emission of very high-energy neutrinos from astrophysical sources, but also the prove the appearance of $\nu_\tau$ from $\nu_\mu$ oscillation. Some experiments, NuTel [2, 3] and CRTNT [4], had been proposed to detect such rare but physically important events. Auger detector also has limited capability in detecting Earth-skimming events.

Earth skimming neutrino experiments relies on air shower initiated by tau lepton. There events comes at zenith angle close to 90 degree, where most of existing air shower simulation code fails. We had used a modified version of CORSIKA simulation code in the feasibility study of NuTel [5]. This code rotates horizontal direction to vertical direction and changes the atmospheric density and index of refraction according to original value in horizontal. However, it could not reproduce the small variation of atmospheric density, which produces asymmetric distribution in shower development in vertical direction.

Recently, CORSIKA released a new version which can simulate events up to zenith angle of 88 degree. We evaluate this new version and compare results with our previous version.

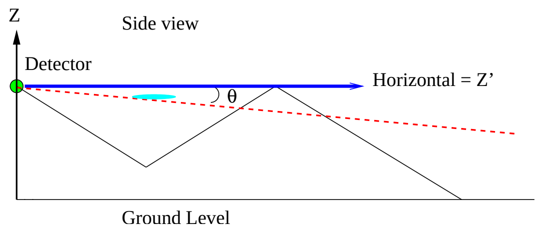


Figure 1: Coordinate rotation used in this study.

## Air Simulation by a modified CORSIKA code

First we rotate local coordinate, shown in figure 1, so horizontal direction become Z axis, which is vertical in CORSIKA code.

Figure 1 Coordinate rotation used in this study. Events coming from zenith angle $\theta$ is rotated to new Z' axis with new zenith angle $\theta' = \theta - 90^o$.

The second step finds the distance from particle injection points to detector. The injection point is determined from the decay point of tau lepton. The neutrino direction, exit point, and decay position are simulated by a code SHINIE [6]. Then the decay of tau lepton is simulated by TAUOLA code, which output daughter particle type and four-momentum of each daughter particles. If a daughter particle is not neutrino, we then put it into shower simulation with proper particle ID and energy.

The third step is shower simulation using CORSIKA. Our code are modified from standard CORSIKA 6.0 and replaced three value/functions with mean value/function along shower track[5]. They are atmospheric density, index of refraction, and photon absorption (extinction) length.

To obtain Cherenkov photon density at a plane perpendicular to shower track, we use a ground array to sample Cherenkov photons. Then 2-dimensional photon density is converted to one-dimensional lateral profile of Cherenkov photon density. Figure 2 shows Cherenkov photon density for incoming electron and pion of 1.E14 eV, 1.E16 eV, 1.E18 eV and injected at distance 20 km from detector.

Since the shower developed completely well before detector, the Cherenkov ring is easily visible from lateral profile for electron shower. For pion shower, Cherenkov photons from muon bundle near shower core still dominated.

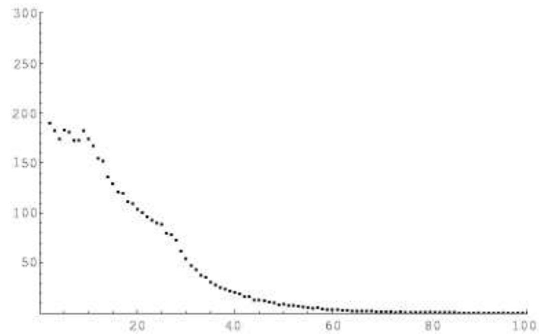


Figure 2: Cherenkov lateral profile initiated by electrons at zenith angle 88 degree. This profile is simulated by recent CORSIKA as described in this section.

## Results from new CORSIKA simulation

For the updated CORSIKA (version 6.66), we simulate similar events at zenith angle 88 degree. These results are shown in Figure 3.

## Discussions

We first compare showers simulated with or without slanted options at zenith angle 88 degree. Both longitudinal profiles have similar Xmax (depth of shower maximum). However, shower size Nmax (number of charged particles at shower maximum) simulated with slant option reduce to almost 60% of that without slant option.

The longitudinal distribution of Cherenkov photons are quite different too. For simulation with slanted options, the Cherenkov photons distribution consists of many small peaks and the overall distribution do not proportional to charged particle distribution. In some case, the primary particle produces very large number of Cherenkov photons. It seem that the Cherenkov photons production in slanted option do not produce Cherenkov photons properly.

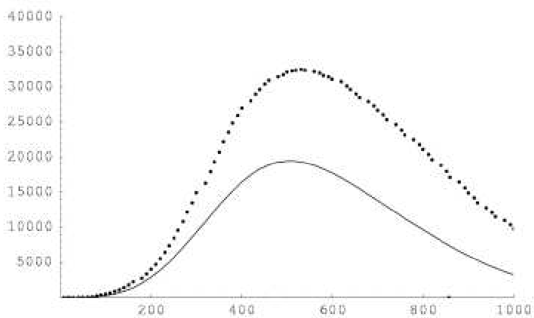


Figure 3: Longitudinal profile of charged particles simulated with (solid line) and without slant option (dot line).

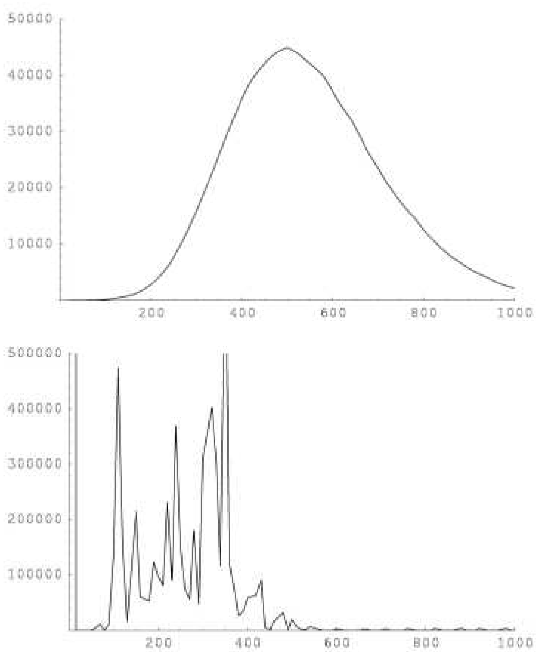


Figure 4: Longitudinal profile of charged particles (top panel) and Cherenkov photons (bottom panel) simulated with curved and slant options. Those figures com from the same event. The first bin of Cherenkov photons is $1.5^9$, which is clearly an error.

This discrepancy also show up in Cherenkov photon lateral and longitudinal distributions. Cherenkov photons lateral profile simulated with rotated geometry behave similar to regular vertical shower. Cherenkov photon numbers simulated with new CORSIKA and at zenith angle 88 degree is almost 1/3 of vertical shower.

## Summary

We had compare longitudinal profile of charged particles and Cherenkov photons by various CORSIKA simulation code. Two major disagreements were found. Cherenkov photon production seems have trouble in slanted option. Shower profile do not agree at vertical and horizontal direction. It is necessary to update these codes to give self-consistent results for near horizontal air shower.

## References

[1] R. Gandhi, C. Quigg, M. H. Reno, I. Sarcevic, Neutrino interactions at ultrahigh energies, Phys. Rev. D58 (1998) 093009.

[2] M. Huang, Expected performance of a neutrino telescope for seeing agn/gc behind a mountain, Nucl. Phys. B (Proc. Suppl.) 118 (2003) 516.

[3] P. Yeh, et al., Pev cosmic neutrinos from the mountains, Mod. Phys. Lett. A19 (2004) 1117–1124.

[4] Z. Cao, M. A. Huang, P. Sokolsky, Y. Hu, Ultra high energy nu/tau detection using cosmic ray tau neutrino telescope used in fluorescence / cerenkov light detection, J. Phys. G31 (2005) 571–582.

[5] M. Huang, C. Hsu, P. Yeh, Monte-carlo simulation of horizontal air shower, Proc. of 28th ICRC (Tsukuba, Japan) (2003) 583–586.

[6] M. Huang, Shinie: Simulation of high energy neutrino interacting with the earth, Nucl. Phys. B (Proc. Suppl.).