Simulation of Horizontal 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:

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 []. 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.

Air Simulation by modify CORSIKA code

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

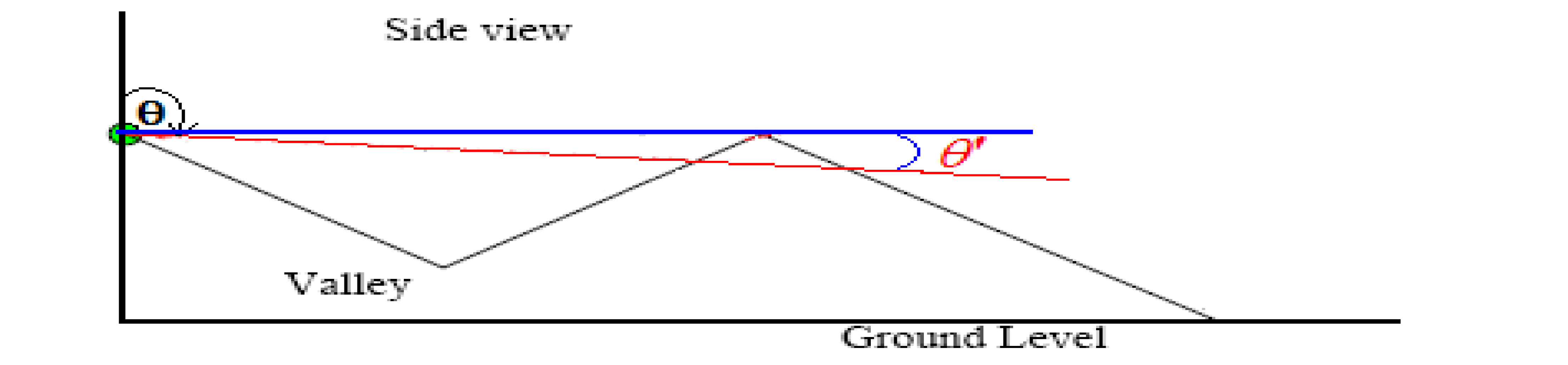

Figure 1 Coordinate rotation used in this study. Events coming from zenith angle Θ is rotated to new Z' axis with new zenith angle Θ'.

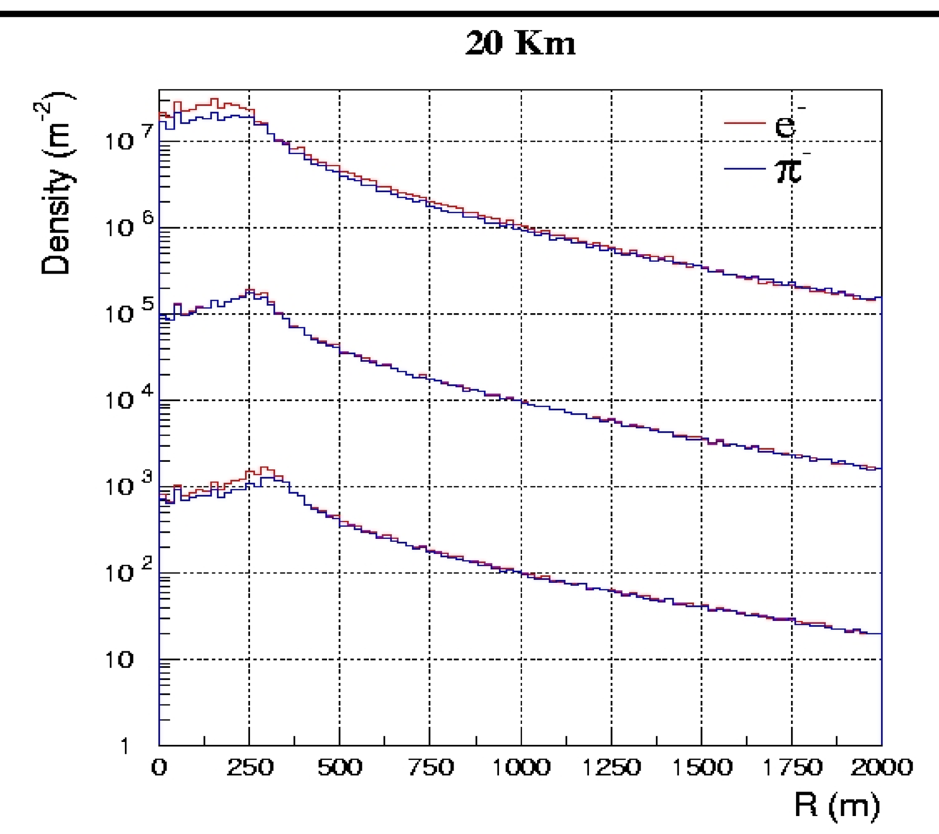

Figure 2 Cherenkov photon lateral profile for electron and pion shower injected from horizontal direction at 20 km from detector. The primary energy are 1.E18 eV, 1.E16 eV, and 1.E14 eV from top to bottom.

Results from new CORSIKA simulation

The standard CORSIKA recommend the zenith angle limitation is 70°. For the updated CORSIKA (version 6.611) with the the CURVED option the zenith angle limit up to 90°,for the CURVED combined with the CERENKOV option the upper zenith angle limit reach 88°. In this new simulation, the Cherenkov detector array be setup at 1100 meter in altitude, and array center at the origin(x=0,y=0), shown in the Figure 3.Results are shown in Figure 4. Finally,we use those options to simulate similar events at zenith angle 88 degree. Figure 4 shows Cherenkov photon density for incoming electron and pion of 1.E14 eV and incident zenith angle at 88°.

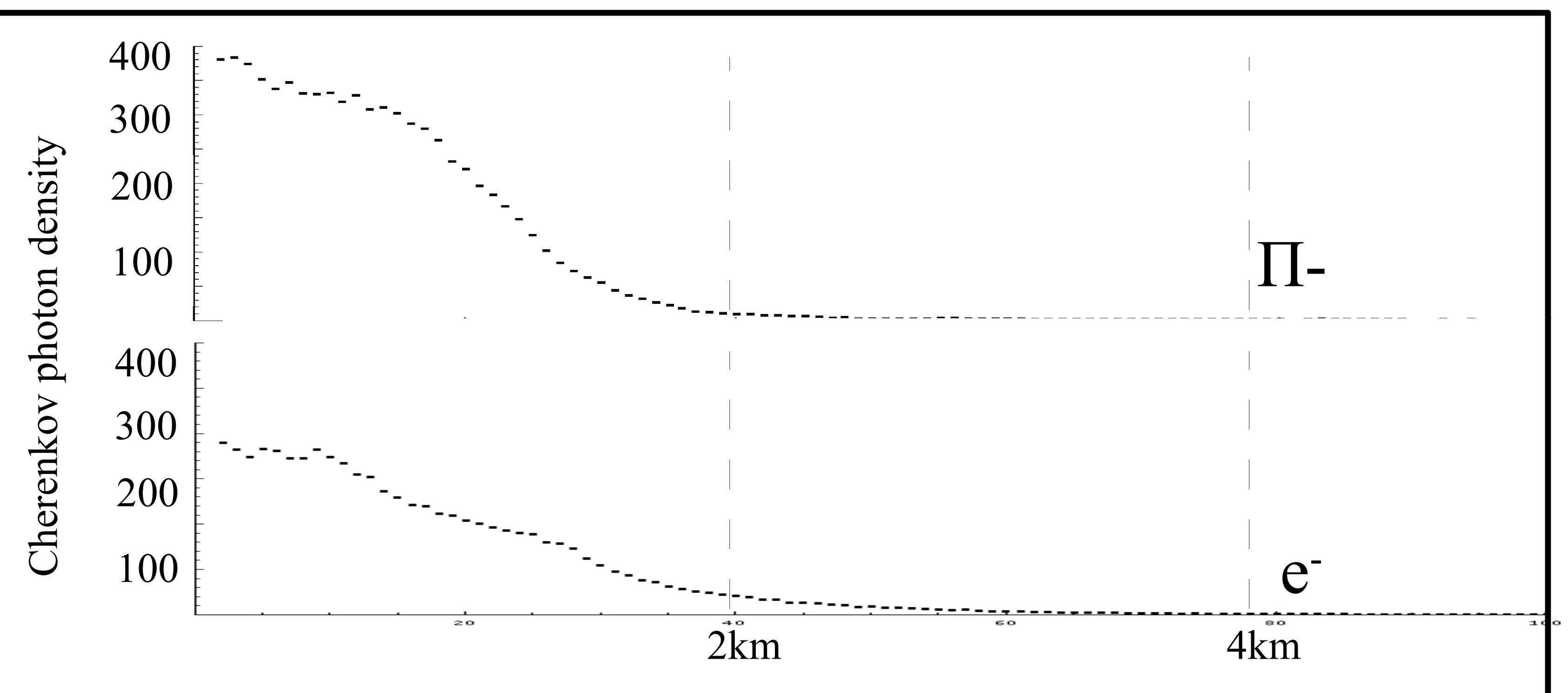

Figure 4: Cherenkov photons lateral density simulated by CORSIKA version (6.611). The primary particle carries 1.E14 eV incident to the detector from 20km at zenith angle 88 degrees.

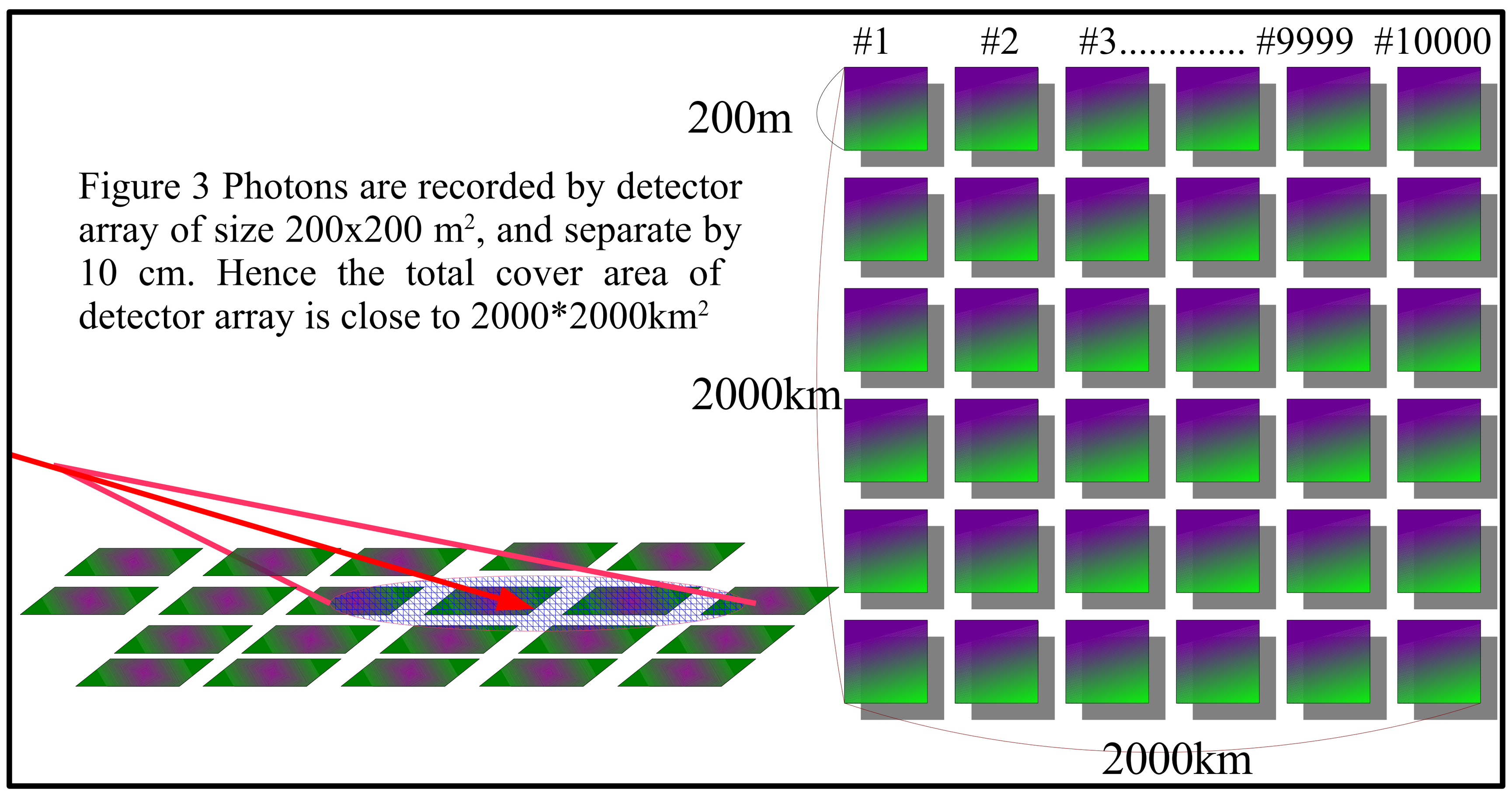

Figure 3 Photons are recorded by detector array of size 200x200 m^2, and separate by 10 cm. Hence the total cover area of detector array is close to 2000*2000km^2

Discussions

In the new CORSIKA version , the zenith angle limit had up to 90 degrees ,hence the horizontal shower simulation is possible running under the CORSIKA. But it still take a lot of computer time to generate enough event to flat the statistics err. Because the hadronic will generate a few of shower which far away the orientation of primary hadron. It cause some sub-shower

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