ICRC'07 Mérida, México

Cosmic Ray Background Simulation and Selection of Tau Neutrino Events of the CRTNT Experiment

J. LIU[1], M. ZHA[1], Z. CAO[1], B. ZHANG[1], T. C. LIU[2], G. L. LIN[2]
[1]*Institute of High Energy Physics, CAS, Beijing 100049.*
[2]*Institute of Physics, National Chiao-Tung University, Hsinchu300.*
liujl@mails.ihep.ac.cn

Abstract: A Tau lepton can be produced in a charged current interaction of cosmic ray tau neutrino with material inside a mountain. If it escapes from the mountain, it will decay and initiate a shower in the air, which can be detected by air shower fluorescence/Cerenkov light detector. A Monte Carlo simulation for Cosmic Ray Tau Neutrino Telescopes (CRTNT) detector near Mt. Balikun in Xinjiang, China, is performed. The results of cosmic ray events, as the background of neutrino detection, and neutrino events selection against cosmic ray background are presented in this paper.

Introduction

A point source search could be a useful approach for solving the long time standing problem of unknown sources of the cosmic rays above 10^{15} eV (1PeV). Observations of neutral particles, which can be directly traced back to the source, is the unique way to perform the searching under 10^{19}eV. Above 10^{14}eV, the neutrino is the only choice to explore remote cosmic ray source because photons will be absorbed by the 2.7K cosmological microwave background[8].

Neutrinos convert into electrons, muons and taus through the charged current interaction depending upon their flavor. However, electrons will shower quickly inside the target material. Muons travel very long distance before they decay but only can be detected by the small energy loss along the trajectory[8]. Using a special mountain as convertor, tau neutrino can convert into tau lepton inside mountain and induce a shower in the air by its decay products, mainly electrons and pions, before they reach to the detector. The CRTNT experiment is proposed to detect tau neutrino by measuring those air showers behind a mountain.

Cosmic rays are strongly suppressed because they are screened by the mountain in front of the detector. However, due to a limited angular resolution of the CRTNT detector, cosmic ray showers coming from directions above the mountain still make a large contamination. Therefore, cosmic ray showers distributed in the zenith angle range from 70^o to 75^o (for the elevation angle of mirror up edge is 73^o) have to be cut during neutrino induced shower search.

The CRTNT detector

The proposed CRTNT project uses fluorescence/Cerenkov light telescopes[4] and the candidate site is Mt. Balikun, about 130 km north of Hami, Xinjiang province, China. It is an excellent candidate of the CRTNT observatory for neutrino search. The north side of the east-west mountain is quite steep. The height of the mountain keeps above 4000 m a.s.l. for more than 30 km in east-west direction. The plateau at north of the mountain stretches hundreds of km at a height of about 1600 m a.s.l. Total precipitation is less than 200mm per year.

Four sites are proposed for the CRTNT experiment. At each site, four telescopes observe an area of the mountain with 64^o in azimuth and 14^o in elevation. Only three sites are used in the simulation, denoted as FD1, FD2, FD3. More detailed description about telescopes system is in[8, 7].

ICRC 2007 Proceedings - Pre-Conference Edition

Simulation

In the simulation, neutrino and cosmic ray (CR) events are simulated separately. The flux of primary neutrinos and CRs is assumed to be isotropic and uniform in the field of view of the detector.

cosmic ray simulation

As a background of neutrino detection, cosmic ray showers, with core location limited in $20km \times 10km$ around the detectors described in last section, are simulated. Showers are coming from an interval of zenith angle between 70^o to 75^o and azimuth angle from 0^o to 180^o. The energy of showers is set between 10PeV to 1EeV and an E^{-3} spectrum is assumed. The shower energy, core location and direction are selected randomly. Showers are parameterized by using three parameters, the position of shower maximum x_{max}, the maximum number of charged particles N_{max} and the width of shower σ_s. Shower longitudinal development is described by a functional form of[5]

$$N_{ch}(x) = N_{max} exp\left\{-\frac{2(x-x_{max})^2}{\sigma_s^2(x+2x_{max})^2}\right\}, \quad (1)$$

where N_{max} is a function of shower energy E, based on the observational result in[2]

$$N_{max} = 0.61 \times E/GeV, \quad (2)$$

x_{max} is parameterized as[4]

$$x_{max} = 740. + 60. \times log10(E/EeV), \quad (3)$$

and $\sigma_s = 0.2$[9]. All detailed descriptions about photon production and light propagation are the same as neutrino simulation that can be found in[8].

A signal finding algorithm based on a running window technique is developed to form a trigger for individual channel. That is the first level trigger which requires the signal-noise ratio to be great than 4σ, where σ is the standard deviation of the total photon-electron noise within a running window of 640ns. The second level trigger is telescope trigger, which requires at least 6 triggered tubes forming a pattern of straight line or 7 triggered tubes forming a pattern of solid circle within a 6×6 running box over a single telescope camera of 16×16 pixels. The third level trigger(event trigger) is that at least one telescope is triggered.

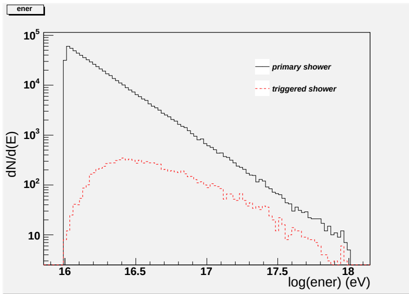


Figure 1: primary cosmic ray event energy distribution(solid line) and triggered event energy distribution(dash line).

As a quick check of the background, all shower to shower fluctuations are omitted. A more realistic simulation using Corsika and Aries is in progress.

For such a simulation being carried out at large zenith angle, a slant atmospheric depth and the earth curvature are taken into account. An approximate mountain profile is assumed in the simulation algorithm which is about 8 km away from the detector.

neutrino simulation

Neutrino interaction in rock, tau lepton decay outside rock, the generation of shower lib, photon production and light propagation are described elsewhere[8, 6]. The electronics trigger model is the same as that in cosmic ray simulation described in last section. A further modification and optimization of neutrino simulation arithmetic are in progress.

Predict cosmic ray event rate

For events with energy below 10^{16} eV can not trigger our detectors, the cosmic ray event energy range is chosen to be above 10^{16} eV. The trigger efficiency is 1.57% for cosmic ray showers. The input energy spectrum and triggered

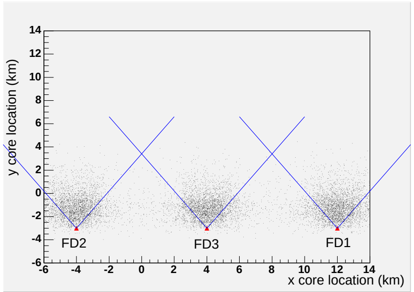


Figure 2: shower core locations of cosmic ray events. The triangle represent CRTNT telescopes. The solid lines attached to the detectors indicate the FOV of the telescopes

event distribution is shown in Figure 1. Figure 2 shows the triggered event core location and the configuration of CRTNT detectors. Event rate of cosmic ray showers is calculated using average flux J(E)=$2 \times 10^{24}/E^3(eV^{-1}.m^{-2}.s^{-1}.sr^{-1})$[3], where 15% duty cycle is assumed. About 11655 events will be expected per year. We use AGN neutrino source model[1] in neutrino simulation. The trigger efficiency for τ lepton is 11.0%[8], and 7.56 ± 0.05 neutrinos can be expected per year under same assumption of the duty cycle according to[8].

Neutrino event selection

Two types of showers, initiated by neutrinos or cosmic rays, have very different characteristics because they are developed in different part of atmosphere and directions. It is quite straight forward to establish a selection algorithm to pick the neutrino events out from generated data set even without a detailed shower reconstruction. In this section, such a selection algorithm is developed by sorting the simulated neutrino showers[8] into five types and picking them out according to their characteristics.

(1) neutrino Cerenkov event.

Triggered tubes get together to form a cycle at the head of the image and other tubes with dim signals form a widely spread out tail behind the head. If such kind of Cerenkov dominant events starts from a high elevation, it still could be a cosmic ray event. A further constraint on the central mass of the image (calculated as a tube signal weighted average image position) being low elevations(less than 11^o), is sufficient to suppress all cosmic rays. The neutrino Cerenkov event is shown in Figure 4. a). Corresponding efficiency of neutrino selection is 5.7%.

(2) horizontal event

For a category of events that the plane determined by axis of shower and detector(SDP) is almost horizontal. If the tube signal weighted center of the image lies on the lower half of the mirrors which corresponds to low elevations, it must be a neutrino event as shown in Figure 4. b). The selection efficiency for this type of neutrino is 21.9%.

(3) long event

Images of this type of showers run through all mirrors at one site, and the tube signal weighted center is also very low in elevation as shown in Figure 4. c). 20.4% neutrino events are picked out.

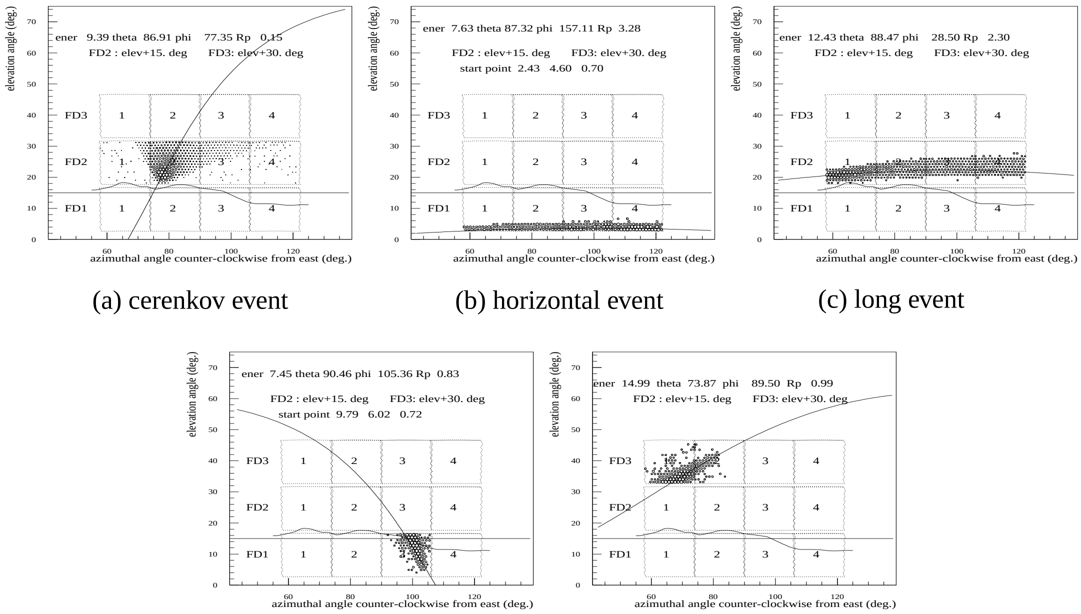
(4) up-going event

Along the SDP, FADC timing information recorded by tubes show that this type of showers are clearly moving upwards, which is shown in Figure 4. d). 28.5% neutrino events can be selected in this way.

(5) back-to mountain event

This type of showers have clear initial location that can be traced back to an area in the detector FOV that is certainly covered by the mountain. To surely recognize this characteristics, the image of the photons must start at the inner part of the mirror, i.e. certain distance away from boundaries of the detector FOV. It is a rather strong indication that a shower in this category must be induced by a neutrino. This type of showers is shown in Figure 4. e). 7.8% neutrino events belong to this category.

All together, about 84.3% selection efficiency is observed among simulated neutrino showers. The rest, which failed being picked out, are all measured by a small portion of detector FOV that the majority of tubes in the image are either in corners or on boundaries of the detector FOV. Applying this event selection algorithm to 11655 cosmic ray events, none of them is picked out. Subtraction efficiency of the cosmic ray background event is almost 100%.



(a) cerenkov event (b) horizontal event (c) long event

(d) up-going event (e) back-to mountain event

Figure 3: five types of simulated neutrino showers. The dash lines show the boundary of the filed of view of each telescope. The solid line along the shower direction represent the SDP. Circles represent the triggered tubes, and the size of each circle is proportional to the signal normalized by the maximum signal of the tube in one shower.

Conclusion

A complete simulation chain including neutrino interaction, tau lepton decay, air shower development, detector responses, triggering and neutrino event selection algorithm is constructed and still in development by adding more realistic fluctuations. According to the result of previous simulation[8], where a conceptual detector was assumed, the τ neutrinos event rate is found to be 7.56 ± 0.05 per year. The modification and optimization are in progress. Based on a parametrization of cosmic ray event distributions, isotropic cosmic rays yield a background in a zenith angle region (70^o,75^o) of 11655 events per year. The neutrino event selection algorithm based on shower image characteristics, picked out 84.3% neutrino events with almost zero impurity. All the cosmic ray background can be suppressed, a detailed reconstruction is also in progress.

References

[1] Semikoz D and SigI G et al. *J. Cosmol. Astropart. Phys.*, 3, 2004.

[2] Victor de Souza. *Phys. Rev. D*, 73:043001, 2006.

[3] Abbasi R.U. et al. *Astro-ph*, 3:0208301, Dec 2004.

[4] Abu-Zayyad T et al. *Astrophys. J.*, 557:686–699, 2001.

[5] Abu-Zayyad T et al. *Astropart. Phys.*, 16:1–11, 2001.

[6] Dutta S. I. et al. *Phys. Rev. D*, 63:094020, 2001.

[7] H. He et al. *this proceeding(2007).*

[8] Z Cao et al. *J. Phys. G: Nucl. Part. Phys.*, 31:571–582, 2005.

[9] B. Zhang et al.(HiRes Coll.). *this proceeding(2007).*