Study of a large array to detect ultra high energy tau-neutrino

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The PeV cosmogenic neutrino is still interesting argument. Since cosmogenic neutrinos interact weakly with matter, the detection of their direction will precisely point out the source in the space. In this paper, we show the results of the simulation of tau lepton air showers induced by high energy neutrinos detected by an array of stations designed to use the Earth Skimming method improved by the “mountain chain screen” strategy. Both track time stamp and position information of the stations on the array are used to reconstruct the shower to estimate the direction and the number of events. The array studied consists of 640 stations (40 × 16) spread over an area of 0.6 km² starting from 1500 m above the sea level (a.s.l.) on 30° inclined plane of the mountain. When we extrapolate to 3 years and 10 km² we estimate 13 tau lepton events in energy interval of 10 PeV to 1000 PeV detected using the present upper limits of tau neutrino flux.

Keywords: Ultra High Energy Cosmic Rays, Tau-Neutrino, Ground Based Array, Earth Skimming Strategy, CORSIKA

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1. Introduction

The observation of Ultra High Energy (UHE) neutrinos generated in both distant galactic and extra galactic sources such as pulsars or supernova remnants have been a major challenge in astroparticle physics. The neutrinos with an energy of $10^{17}$ eV or more, generated by interaction of Ultra High Energy Cosmic Rays (UHECRs) with the Cosmic Microwave Background (CMB) are called cosmogenic neutrinos [1]. Because of the low neutrino flux and the small detection probability, a very large scale detector array (surface or volume) is required to get a detectable rate. For this purpose, many large array experiments based on different techniques have been constructed [2, 3, 4, 5, 6, 7, 8].

Recently the IceCube Collaboration [9] has reported 28 neutrino candidate events in the energy range of 30 to 1200 TeV. They also claimed the detection of a high-energy neutrino event, IceCube-170922A, with an energy of $\sim 290$ TeV in correlation with other telescopes showing a multimessenger physics. The arrival direction of this neutrino was consistent with the location of a known $\gamma$-ray blazar, TXS 0506+056, observed to be in a flaring state [10].

The cosmogenic neutrino, such as tau neutrino ($\nu_\tau$), may interact along the chord of the Earth or inside a mountain chain and creates a tau lepton ($\tau$) by the charged-current (CC) interaction. When the $\tau$ emerges from the rock before it decays, it produces an extensive air shower developing at very large angle near to the horizon [11, 12]. The observations can be achieved using surface detectors, Cherenkov light telescopes, fluorescence detectors or radio signals. Some of the proposed experiments in the literature are Ashra-1 [13], MAGIC telescopes [14], Telescope Array (TA) [15], and IceCube [16, 17].

The Ashra-1 detector aims to observe the Cherenkov lights from $\tau$ showers with Earth Skimming method for PeV-EeV energy range [13]. An upper limit of neutrino flux has been measured by MAGIC telescopes in the 1 PeV to 3 EeV energy interval for $\nu_\tau$ induced showers arising from the ocean [14]. In Antartica, radio antennas are placed to the ground and point at the high mountains to detect the skimming $\nu_\tau$s too [18]. All these proposed experiments have no evidence of $\tau$ events except a possible $\tau$ candidate in IceCube [16, 17]. To detect the horizontal and upward $\nu_\tau$ showers, we propose a surface detector array on an inclined plane to improve the detection acceptance of $\tau$ shower using the time of flight (TOF) and e/mu separation [19, 20]. In this study we also include a chain of mountain in front of the array and evaluate the wideness of the valley.

This paper shows the results of a large array named as “TAUshoWER”, (TAUWER) which has the geometrical advantage of using both the Earth
Skimming method to detect the $\tau$ showers produced below the horizon and a mountain chain in front of the array to enlarge the acceptance. The array geometry is discussed in Section 2 while the simulation of the decaying $\tau$ air showers, the selection criteria for decay length from emerging point and the result of the probability calculations for tau-neutrino interaction are given in Section 3. Analytical approach on the estimation of the event number to be observed with this array is presented in Section 3.1. Reconstruction of the showers is given in Section 3.2 and Section 3.3. Section 3.4 contains a discussion of the trigger. Finally, we summarize our results and conclude with number of expected event/year.

2. Design of the Array

To detect the $\tau$ showers produced by the tau-neutrino interaction with rock along its path in the Earth crust or a mountain in front of the array, we propose a large surface array in which stations point below the horizon to detect particles produced by large angle showers. The best way, as discussed in Section 3, to detect $\nu_\tau$ is to use large amount of matter by pointing down the horizon and a mountain chain in front of the array to increase the interaction probability of $\nu_\tau$. Therefore, we propose to install stations on an inclined mountain surface. In this paper, we consider a grid of 640 stations ($40 \times 16$) placed 30 m apart and located on 30° inclined plane of the mountain between 1500 m and 2250 m above the sea level and covering a surface of 0.6 km$^2$ as shown in Figure 1. Each station, named tower, is composed by two scintillator tiles ($40 \times 20 \times 1.5$ cm$^3$) 160 cm apart and read by 3x3 mm$^2$ silicon photomultiplier (SiPM) placed on one side, which permit to select the particle direction using the time of flight (TOF) method. If a layer of lead 2.5 cm thickness is installed in front of the rear tile it is possible separate the muons from the electromagnetic particles [20]. The stations point below the horizon (approximately 2.5°) to measure upward moving showers coming from $\nu_\tau$ interactions with the Earth crust and at the same time can detect showers produced in the mountain chain. Shower direction is selected by the TOF computed with the two scintillating plates. The layout of the array studied in this paper covers a surface of 0.6 km$^2$ which can be increased according to the shape of the mountain.

3. Evaluation of $\tau$ events escaped from the rock

The detection of high energetic $\nu_\tau$ which are coming nearly horizontal to the Earth surface has a chance to create a $\tau$ via a charge-current (CC) interaction or neutral-current (NC) interaction. It may survive and emerge from the surface to initiate a shower in the atmosphere. In order to take
Fig. 1. Schematic drawing (scaled) of the array. The array consists of 640 stations placed on the 30° inclined plane (mountain surface) in the matrix form of 16 rows and 40 columns which are separated by 30 m apart.

advantage of both valley and mountain to improve the detection probability, each station in the array is placed on the mountain slope and directed to the horizon. The shower detection probability depends on not only \( \tau \) initial energy but also traveling distance of the \( \tau \) after the \( \nu_\tau \) interaction inside the Earth crust. Therefore, we have considered a mountain in front with 60 km thickness which corresponds to maximum travel distance for \( \tau \) with an energy of 1000 PeV to escape from the rock before it decays as shown in the sketch of the proposed experiment for this study (Figure 2). The incoming \( \nu_\tau \) travels a distance \((L - x)\) along the Earth crust and interacts with the rock as depicted in the asterisk symbol, “∗” and produce \( \tau \) by CC interaction. The \( \tau \) travels a distance \( x \) before emerging from the rock. \( L^∗ \) is the distance between the point where \( \tau \) initiates the shower and the center of the array. In this study, we have required that \( \tau \) shower is produced in atmosphere.

To evaluate the expected \( \tau \) events detected by the array we first generated events using the TAUOLA code [21] considering several decay modes
Fig. 2. In this layout (not in scale) the array accepts \( \tau \) shower produced by charged current interaction skimmed neutrinos by the Earth crust and a mountain in front of the array. \( L - x \) is the interaction distance for the \( \nu_\tau \), the interaction point shown by an asterisk symbol “\(*\)”, \( x \) is the traveling distance for the \( \tau \). \( L^* \) is the distance of \( \tau \) decay point from the center of the array.

of the \( \tau \) in the energy range of 10-1000 PeV. We have considered the decay modes \( (\pi^- , \pi^- \pi^0 , \pi^- \pi^+ \pi^- , \pi^- \pi^0 \pi^0 , \pi^- \pi^+ \pi^- \pi^0) \) that covers 64% of the \( \tau \) branching ratio to study the optimization and identification performance of the expected \( \nu_\tau \) induced showers by TAUWER array.

Consequently, CORSIKA (version 6.99) [22] has been modified and compiled to simulate very inclined showers at an observation plane which is considered to be 30°. The produced air showers, induced by the decay products of \( \tau \), were initiated at 1500 m a.s.l. and developed up to the detector level (2250 m a.s.l.) for 4 different distances starting from the \( \tau \) decay point to the center of the array, \( L^* \) (3 km, 5 km, 7 km and 10 km), as shown in Figure 2. 1000 showers have been simulated at different energy for this study. QGSJETII [23] and GEISHA [24] are selected for high and low energy interaction models, respectively. “CURVED EARTH” and “SLANT” options are activated to make more realistic simulation for correctly include the atmospheric depth. “COAST” option is selected for reading and converting CORSIKA binary files. Since the computing time of the showers increases with the energy, the “thinning” strategy has been also used in shower productions. The CORSIKA output file provides position \((x, y \text{ and } z)\), arrival time and momentum \((P_x, P_y, P_z, \text{ and } P_{tot})\) informations of each particle crossing on the observation plane. Using these informations the trajectory is reconstructed for each particle and counted when it passes trough the scintillating tiles. In this proposed layout it is also important to identify the best distance of the plane of the array from the \( \tau \) decay point to in-
tercept the maximum shower evolution to make more efficient the shower detection and in the some time evaluate the best valley wideness.

Fig. 3. Averaged number of $e^\pm$ per shower (among 180 simulated showers) detected on the array as a function of $L^*$, distance of $\tau$ decay point to the center of the array, for different energies ($10^7$, $5 \times 10^7$, $10^8$, $5 \times 10^8$, $10^9$ GeV) at $\pi^-\pi^0$ decay mode.

The determination of the optimum wideness for the valley is evaluated using the particle density measured on the array plane for different decay paths of the $\tau$ in air. Figure 3 shows the averaged number of the $e^\pm$ per shower detected on the array plane for $\pi^-\pi^0$ modes at different energies (10 - 1000 PeV) as a function of $L^*$, the distance of the $\tau$ decay point to the center of the array. The number of muons is about 5% of the number of electrons and almost flat as a function of the distance of $\tau$ decay point in the air. It shows that the number of $e^\pm$ from the $\pi^-\pi^0$ decay mode and different $\tau$ energy on the detector plane is maximum when the $\tau$ decay point is at a distance of 5-7 km from the center of the array. A similar distribution is also obtained by $\pi^-, \pi^-\pi^+\pi^-, \pi^-\pi^0\pi^0$ and $\pi^-\pi^+\pi^-\pi^0$ decay modes. The decrement on the density of $e^\pm$ at 10 km is due to the energy loss of $e^\pm$ in the atmosphere. Since the density of the detected particles is higher at 5-7 km, 7 km decay lengths from emerging point to the array center is used for further analysis in this text. To obtain the expected number of neutrino $\tau$ detected by the array we have to evaluate the probability of escaping of the $\tau$ from the Earth crust, $P_{escp}$. The probability of $\nu_\tau$ interacts along the $L - x$ path at * point inside the rock is given as
\[ P_{\text{int}} = \int_0^{L_x} e^{-l/L_{\text{int}}} \frac{dl}{L_{\text{int}}} \]  

where \( L_{\text{int}} \) is the neutrino interaction length, \( dl \) is the short distance the interaction happens. The neutrino cross section for charged current interaction within 10% as follows according to CTEQ6.6M [25] and its energy dependence varies as \( E_{\nu}^{-0.345} \) where \( E_{\nu} \) is the \( \nu_{\tau} \) energy. By this parameterization we have an interaction length of \( \tau \) about 700 km for 10 PeV and 3000 km for 200 PeV. The neutrino NC cross section is 2.4 smaller than that of CC interaction which means the interaction length of neutrino is about two times greater than that of charged current channel. Since the NC interaction probability is no high before the CC interaction, the neutrino has the same energy as it enters the Earth shell when it interacts as CC. In this study we consider CC interactions of \( \nu_{\tau} \) where the \( \tau \) lepton is produced with 80% of the \( \nu_{\tau} \) energy [26] as well as the NC interaction.

On the other hand, the probability the \( \tau \) escapes from the Earth shell is given by the probability the neutrino interacts along its path times the survival probabilities of \( \tau \) lepton in the shell with an initial energy as a function of the distance it travels, given as

\[ P_{\text{escp}} = P_{\text{int}} \times \exp \left[ -\int_0^{L} (ct_0 (\exp[-\beta_0/\beta_1 + (\beta_0/\beta_1 + \ln(E_i/E_0)))\exp[-\beta_1 \times \rho_{\text{rock}} \times (E_0)/m_{\tau})^{-1} dl \right] \]  

where \( l \) is the distance the \( \tau \) travelled, \( c \) is the speed of light, \( t_0 \) is the mean life time of \( \tau \) lepton, \( \beta_0 \) is the energy loss parameter from Bremsstrahlung, pair production and photonuclear interaction with \( E_0 = 10^{10} \) GeV, \( E_i \) is the energy of \( \tau \) lepton when it is generated, \( \rho_{\text{rock}} = 2.65 \times 10^{15} \) (g/km³) is the density of the standard rock, and \( m_{\tau} \) is the mass of \( \tau \) lepton, \( \beta_1 \) is the photonuclear coefficient as function of neutrino energy [27, 25, 28]. The maximum distance the \( \tau \) lepton travels at the energy of 1000 PeV is about 60 km. That means the neutrino interaction should happen in the Earth shell of 60 km thickness to produce a tau lepton which has a probability to escape from the Earth crust. The survival probability \( (P_{\text{surv}}) \) of \( \tau \), is correspond to the exponential factor in Eq. 2, decreases while \( \tau \) lepton moves away from the interaction point in the Earth shell.

### 3.1. Estimation on the number of detected \( \nu_{\tau} \) events

As discussed in Section 3, we evaluated the \( \nu_{\tau} \) interaction length and its probability \( P_{\text{int}} \) based on the study given in Ref.[26], besides that the approaches are used from Ref.[29] to calculate the \( \tau \)'s \( P_{\text{surv}} \) and then the escape probability, \( P_{\text{escp}} \) after the \( \tau \) travels through the Earth and the mountain chain 60 km thickness at PeV energies. Table 1 shows the \( P_{\text{escp}} \) of the
\( \tau \) calculated for different neutrino initial energies and escaping directions from the Earth crust using the formula 2. The \( \tau \) crossing the mountains are produced at 90° in \( \theta \). No specific profile of the mountain has been studied.

Table 1. The escape probability of \( \tau \) as function of \( \theta \) and \( \nu_\tau \) energy. In the first row is reported the probability considering a mountain screen 60 km thickness. These values where computed using a neutrino cross section for charged currents according to CTEQ6.6M.

| \( E \) / Energy (FWI) | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Screen                  | 6.650 \times 10^{-2} | 3.650 \times 10^{-3} | 9.430 \times 10^{-3} | 1.546 \times 10^{-2} | 2.220 \times 10^{-2} | 2.651 \times 10^{-2} | 3.245 \times 10^{-2} | 4.164 \times 10^{-2} |
| 91                      | 3.140 \times 10^{-2} | 2.038 \times 10^{-3} | 9.656 \times 10^{-3} | 1.908 \times 10^{-2} | 3.278 \times 10^{-2} | 4.203 \times 10^{-2} | 5.384 \times 10^{-2} | 6.609 \times 10^{-2} |
| 92                      | 1.379 \times 10^{-2} | 2.140 \times 10^{-3} | 7.426 \times 10^{-3} | 1.212 \times 10^{-2} | 1.425 \times 10^{-2} | 1.570 \times 10^{-2} | 1.656 \times 10^{-2} | 1.686 \times 10^{-2} |
| 93                      | 5.383 \times 10^{-3} | 1.659 \times 10^{-3} | 4.472 \times 10^{-3} | 5.729 \times 10^{-3} | 5.323 \times 10^{-3} | 4.343 \times 10^{-3} | 3.023 \times 10^{-3} | 1.330 \times 10^{-3} |
| 94                      | 2.070 \times 10^{-3} | 1.138 \times 10^{-3} | 2.496 \times 10^{-3} | 4.105 \times 10^{-3} | 1.966 \times 10^{-3} | 1.245 \times 10^{-3} | 1.182 \times 10^{-3} | 1.171 \times 10^{-3} |
| 95                      | 1.978 \times 10^{-4} | 7.340 \times 10^{-4} | 1.226 \times 10^{-3} | 9.833 \times 10^{-3} | 5.124 \times 10^{-3} | 2.855 \times 10^{-3} | 1.043 \times 10^{-3} | 1.025 \times 10^{-3} |
| 96                      | 1.411 \times 10^{-4} | 4.757 \times 10^{-4} | 6.056 \times 10^{-3} | 3.883 \times 10^{-3} | 1.524 \times 10^{-3} | 5.059 \times 10^{-3} | 2.084 \times 10^{-3} | 2.144 \times 10^{-3} |
| 97                      | 9.818 \times 10^{-5} | 2.784 \times 10^{-4} | 2.938 \times 10^{-3} | 1.519 \times 10^{-3} | 4.515 \times 10^{-3} | 1.712 \times 10^{-3} | 3.704 \times 10^{-3} | 2.453 \times 10^{-3} |
| 98                      | 6.309 \times 10^{-5} | 1.667 \times 10^{-4} | 1.405 \times 10^{-3} | 5.810 \times 10^{-3} | 1.324 \times 10^{-3} | 4.150 \times 10^{-3} | 6.708 \times 10^{-3} | 2.830 \times 10^{-3} |

By using the present cosmogenic neutrino flux upper limit [30, 31, 32], \( \Phi(E) \), we evaluate the expected number of \( \tau \) events in the TAUWER array according to the following formula

\[
N_\tau = \int_{E_{\text{min}}}^{E_{\text{max}}} \Phi(E) P_{\text{esc}}(E)(\varepsilon_{\text{acc}}(E, \Theta, \Phi, L^*) \times \beta_\tau) dE \Delta t \Delta A \Delta \Omega \tag{3}
\]

where \( \beta_\tau \) is \( \tau \) branching ratios for \( \pi^- \), \( \pi^- \pi^0 \), \( \pi^- \pi^+ \pi^- \), \( \pi^- \pi^0 \pi^0 \) and \( \pi^- \pi^+ \pi^- \pi^0 \) decay modes, \( \varepsilon_{\text{acc}} \) is the efficiency of detector array acceptance. \( \Delta t \) is the time interval of one year, \( \Delta A = 0.6 \text{ km}^2 \) area and \( \Delta \Omega \) is the solid angle that watched the showers emerging below the horizon within 8° in \( \theta \) and the showers emerging from the chain of mountain in front of the array of 2° in \( \theta \). To evaluate the number of detected events, we take into account two scenarios: Earth Skimming and the screen strategies produced by a mountain chain in front of the array.

The expected number of events by the TAUWER array was estimated using the latest neutrino flux upper limit reported by IceCube experiment [30, 31, 32]. The results of different scenarios, only skimming strategy and screen strategy are summarized in Table 2. The expected number of events as function of two different neutrino flux upper limits are 0.18 and 0.43 events in \( \text{km}^2 \) per year for skimming and skimming-screen strategy, respectively. If the integrated time is 3 years [32] and the surface of array is 10 \( \text{km}^2 \) the number of expected events for TAUWER array are about 13 events. The presence of ‘screen’ increases the detected number of events about a factor three. That is explained by higher probability of interaction of the \( \nu_\tau \) that travels a longer path when it is skimmed by the Earth crust.

The \( P_{\text{esc}} \) computed using the analytic method has been compared to that evaluated using a specific code DANTON that simulates the tau-
Table 2. The expected number of events in km$^2$ per year for TAUWER array using analytic method and DANTON simulation code corresponding to the different upper limit fluxes. With DANTON simulation we computed only skimming events.

| Flux (GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$) | Scenario           | Energy range (PeV) | $N_{\text{event}}$ CTEQ6.6M | $N_{\text{event}}$ DantonSim |
|--------------------------------------|---------------------|---------------------|-------------------------------|------------------------------|
| $2 \times 10^{-8}$ (all flavor) [30] | Skimming            | $[10 - 1000]$       | 0.0437                        | 0.0885                       |
|                                      | Screen              | $[10 - 1000]$       | 0.1273                        |                              |
|                                      | Skimming + Screen   | $[10 - 1000]$       | 0.1710                        |                              |
| $5.1 \times 10^{-8}$ ($\nu_{\tau}$ flavor) [32] | Skimming            | $[10 - 1000]$       | 0.3245                        | 0.2257                       |
|                                      | Screen              | $[10 - 1000]$       | 0.4361                        |                              |
|                                      | Skimming + Screen   | $[10 - 1000]$       |                              |                              |

Neutrino interaction in the Earth crust and the $\tau$ decay giving the $\tau$ decay point in the air [33]. Using this code we obtained the total $P_{\text{escp}}$ of $\tau$ for energy greater than 200 PeV in average a factor 2.5 higher than the $P_{\text{escp}}$ evaluated with the analytic method. This discrepancy is due mainly to the different PDF used in the neutrino cross section parametrization. To evaluate the expected $\tau$ lepton we can use the geometrical acceptance computed in our study because the tau decay point coordinates in DANTON have an average distance from the array of 8 km and a momentum distribution similar to which was used in the analytic method. By using the upper limit fluxes [30, 32], we obtain 0.21 and 0.55 events per km$^2$ per year with the DANTON simulation code.

3.2. Arrival $\tau$ shower Direction

The direction of the $\tau$ air shower is calculated with a common method used in literature [34] based on the minimization of the direction vectors of each track by using Minuit [35]. The momentum of each particle are used to obtain the direction vectors $(n_x, n_y, n_z)$ of the shower in Eq. 4.

$$
\chi^2 = \sum_i^N w_i \left( n_x(x_i - x_{\text{core}}) + n_y(y_i - y_{\text{core}}) + n_z(z_i - z_{\text{core}}) - c(t_i - t_{\text{core}}) \right)^2
$$

where $t_i$ is the arrival time of $e^\pm$, $x$, $y$ and $z$ its coordinates on the array plane, $x_{\text{core}}$, $y_{\text{core}}$, $z_{\text{core}}$ the coordinates of the core of the shower evaluated with maximum weighted density of the particles on the inclined plane. $t_{\text{core}}$ is estimated from the closest station taken into account of the distance from
Fig. 4. Zenith (top) and Azimuthal (bottom) angles evaluated from active station for different showers where decay length from emerging point is 7 km and primary energy ranges from 10 PeV to 1000 PeV. Active stations are selected by requiring at least two hits on the tower.

the core. The active stations are selected by requiring at least two particles on the tower and used in the evaluation of the shower direction for different showers where the primary in an energy range of 10 PeV - 1000 PeV and the decay point 7 km distant from the array plane.

Figure 4 shows both zenith and azimuthal angles evaluated for sample of 27 showers in the energy range between 10 and 1000 PeV. The arrival directions $\theta$ and $\phi$ are estimated with an error of $0.16^\circ$ and $0.045^\circ$, respectively.

3.3. $\tau$ shower energy reconstruction

The center of the shower is estimated from the most triggered stations and hits per station as function of distance from the shower core is given in Figure 5(a). This figure shows the number of hits per station as a function of distance for different energy intervals between 10 and 1000 PeV where at least one hit on a single tile is required. The core of the shower is evaluated from the stations having at least 5 hits. While the radius of the shower
Fig. 5. a) Number of hits per station versus distance from the shower core for different $\tau$ energies, b) the energy of $\tau$ showers as function of the shower radius.

is obtained by requiring 4 subsequent stations having hits ranging from 1 to 4 and register the first one as the radius (edge) of the shower. The Figure 5(b) shows the energy versus its corresponding radius. It is clearly seen that there is an exponential behaviour between energy and radius in the range of the interested energy region.

3.4. Trigger Decision

The average timing spectrum for $e^\pm$ between 10 PeV and 1000 PeV for all hadronic channels of $\tau$ shower that hit any scintillator in the 640 stations has been studied. The timing spread of the stations is computed by using the arrival time of all hits in the station and identifying the earliest one which is selected as time reference to find a delay time in a $(4 \times 4)$ subarray around the center of the shower. The maximum time difference between the first and last hit produced by the $\tau$ shower on the array plane must be in the time interval of $0.3 \mu s$. From these simulation studies the signature of $\tau$ shower is given by a cluster of station with highest density of $e^\pm$ and the maximum number of hits in a single station for $\tau$ shower between 10 PeV and 1000 PeV ranges from $450 - 3500$, in the time interval of $10 - 20$ ns. Compared this requirement to the vertical EAS events collected in a test made at Karlsruhe Institute of Technology (KIT) [19], the atmospheric background can be easily suppressed if we require 250 hits, defined as trigger T1. The second level trigger T2 can be defined as requiring at least 450 hits on each station of a sub-array ($2 \times 2$) in a time window of 88 ns. This criteria (/trigger) leads to a selection of a shower with an energy of $10^8$ GeV or greater.
4. Conclusions

We have simulated $\tau$ decay modes ($\pi^-$, $\pi^-\pi^0$, $\pi^-\pi^+\pi^-$, $\pi^-\pi^0\pi^0$, $\pi^-\pi^+\pi^+\pi^-$) that covers 64 % of the $\tau$ branching ratio in the energy range of 10 – 1000 PeV to determine the performance of the TAUWER array. It shows that the energy of the showers between 100 and 1000 PeV can be reconstructed in terms of the radius as discussed in Section 3.3. The arrival direction is also determined with an accuracy of 0.16° in the same energy range. The atmospheric background can be easily rejected by requiring T1 trigger while a second level trigger, T2 selects showers with $10^8$ GeV or greater energies. We have estimated the $\nu_{\tau}$ conversion to $\tau$ and $\tau$ propagation through the rock including both skimming and screen strategies with the TAUWER detector array, which is ranging between 5-13 tau lepton events in the energy range of 10 – 1000 PeV for 3 years of integrated time period and an array surface of 10 km$^2$ using the analytical method. We obtained 6-16 tau lepton skimmed events by using DANTON simulation for the same time period, array surface and in same energy range. The number of events skimmed by the Earth crust using this simulation code is higher of a factor two due to the neutrino cross section. The effect of the screen in front of the array increase the expected number of events of a factor three.

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