1. Introduction

The study of ultrahigh energy upward and horizontal $\tau$ air showers produced by $\tau$ neutrino interactions within the Earth crust has been considered in recent years as an alternative way to detect high energy neutrinos. The $\nu_\tau$ UHE sources are more common $\nu_\mu$ (or $\nu_e$) whose tiny masses ($\Delta m_\nu > 5 \cdot 10^{-2}$ eV) and flavour mixing would lead to a $\nu_\tau$ appearance. The results are often difficult to interpret. The problem of $\tau$ neutrinos crossing the Earth is indeed quite complicated because of the complex terrestrial neutrino opacity at different energies and angles of arrival. In addition, several factors have to be taken into account, such as the amount of energy transferred in the $\nu_\tau - \tau$ lepton conversion, as well as the $\tau$ energy losses and interaction lengths at different energies and materials. This makes the estimate of the links between the input neutrino - output $\tau$ air shower very difficult. Such a prediction is further complicated by the existence of a long list of theoretical models for the incoming neutrino fluxes (GZK neutrinos, Z-burst model flux, $E^{-2}$ flat spectra, AGN neutrinos, topological defects).

Many authors have investigated this $\nu_\tau$ signature by their convolution of flux models and the Earth new opacity; however the results are varied, often in contradiction among themselves, and the expected rates may range over a few order of magnitude (Fargion, Aiello, & Conversano 1999; Fargion 2002; Bertou et al. 2002; Feng et al. 2002; Bottai & Giurgola 2003, hereafter BG03; Tseng et al. 2003; Bugaev, Montaruli, & Sokalski 2004; Fargion et al. 2004; Jones et al. 2004; Yoshida et al. 2004). So far, the majority of the current studies on this topic is based on Monte-Carlo simulations assuming a particular model of the incoming neutrino flux. Most of the authors focus on the UpTaus tracks in underground detectors.

To face such a complex problem, we considered the simplest approach: first we disentangle the incoming neutrino flux from the consequent $\tau$ air-shower physics; therefore, to establish the $\tau$ production rate we introduce an effective volume and mass for Earth-skimming $\tau$'s, which is indepen-

Muon and Gamma Bundles tracing Up-going Tau Neutrino Astronomy

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Figure 1. Horizontal Upward Tau Air-Shower (HorTauS) originated by UHE neutrino skimming the Earth: fan-shaped jets arise because of the geo-magnetic bending of charged particles at high quota (\(\sim 23-40 \text{ km} \)). The shower signature may be observable by EUSO just above the horizon. Because of the Earth opacity most of the UpTau events at angles \(\theta > 45-50^\circ\) will not be observable, since they will not be contained within its current field of view (FOV).

We present a very simple analytical and numerical derivation (as well as its more sophisticated extensions) which takes into account, for any incoming angle, the main processes related to the neutrinos and \(\tau\) leptons propagation and the \(\tau\) energy losses within the Earth crust. Our numerical results are constrained by upper and lower bounds derived in simple approximations (see Fargion et al. 2004 for details). The effective volumes and masses will be more severely reduced at high energy because we are interested in the successful development of the \(\tau\) air-shower. Therefore we included as a further constraint the role of the air dilution at high altitude, where \(\tau\) decay and the consequent air-shower may (or may not) take place.

We showed (Fargion et al. 2004) that our results give an estimate of the \(\tau\) air-shower event rates that exceeds earliest studies but they were comparable or even below more recent predictions (Yoshida et al. 2004). Secondly, we point out here, for the first time, that the consequent \(\mu^\pm, e^\pm, \gamma\) signature of HorTaus largely differs from that of horizontal UHECR backgrounds. Finally we introduce in the calculation of the number of events an additional suppression factor related to the altitude at which air showers are observed. This guarantees the optimal extension and the largest flux for the shower to be detected at each observational \(h\) altitude.

2. Effective volume and masses for Hor-Taus

To calculate the effective volume we assume that the neutrino traversing the Earth is transformed in a tau lepton at a depth \(x\), after having travelled for a distance \(D(\theta) - x\). The column depth \(D(\theta)\) defined as \(\int \rho(r)dr\), the integral of the density \(\rho(r)\) of the Earth along the neutrino path at a given angle \(\theta\) is shown in Fig. 2. The angle \(\theta\) is included between the neutrino arrival direction and the tangent plane to the earth at the observer.
where rock and water. As one can see from the picture, primary neutrino energy. The energy label on the location (θ = 0° corresponds to a beam of neutrinos tangential to the earth’s surface) and it is complementary to the nadir angle at the same location. The probability for the neutrino with energy $E_\nu$ to survive until a distance $(D(\theta) - x)/L_\nu$ is $e^{-x/L_\nu(\beta)}$, while the probability for the tau to exit the Earth is $e^{-x/l_{\tau}}$. On the other hand, as we will show in the next section, the probability for the outcoming $\tau$ to emerge from the Earth keeping its primary energy $E_{\tau}$ is $e^{-x/l_{\tau}(\beta)}$ (where $e^{-x/L_\nu(\beta)} \ll e^{-x/l_{\tau}}$ at energy $E_\tau > 3 \times 10^{17}$ eV).

By the interaction length $L_\nu$ we mean the characteristic length for neutrino interaction; as we know its value may be associated to the inverse of the total cross-section $\sigma_{T\nu} = \sigma_{CC} + \sigma_{NC}$, including both charged and neutral current interactions. It is possible to show that using the $\sigma_{CC}$ in the $e^{-x/L_\nu(\beta)}$ factor includes most of the $\nu_\tau$ regeneration along the neutrino trajectory making simpler the mathematical approach.

Indeed the use of the total cross-section in the opacity factor above must be corrected by the multi-scattering events (a neutral current interaction first followed by a charged current one later); these additional relay events (“regenerated taus”) are summarized by the less suppressing $\sigma_{NC}$ factor in the $e^{-x/L_{CC}(\beta)}$ opacity term. The only difference between the real case and our very accurate approximation is that we are neglecting a marginal energy degradation (by a factor 0.8) for only those “regenerated taus” which experienced a previous neutral current scattering. We also neglected all the charged current events deep inside the Earth whose tau lepton birth and propagation is source of lower energy tau neutrinos which pile up at energy $10^{17}$ eV and below; such $\nu_\tau$ regeneration (absent in $\nu_\mu$ or $\nu_e$ cases) may be here neglected because of its marginal role in the range of energy ($>10^{17}$ eV) we are interested in. Therefore our estimates give a lower bound for the detection of $\tau$ air showers from UHE $\nu_\tau$ skimming the Earth. The rarer short range decay of UHE $\tau$ inside the Earth, with a marginal energy loss, may be an additional source of “UHE regenerated” $\nu_\tau$ even at energy $10^{18}$-10$^{19}$ eV; their additional contribution (here neglected) will be discussed elsewhere.

The effective volume per unit surface is given by

$$\frac{V_{Tot}(E_\nu)}{A} = \frac{V_{Tot \pm}(E_\nu)}{2\pi R_\oplus^2} = \int_0^{\frac{\pi}{2}} \int_0^{D(\theta)} e^{-\frac{D(\theta) - x}{L_{\nu CC}}} e^{-\frac{x}{l_{\tau}}} \sin \theta \cos \theta dx \, d\theta \quad (1)$$

where $A$ is any arbitrary surface above the corresponding effective volume. For instance this expression has been first estimated for all the Earth. In this case $A$ is just half of the terrestrial surface, due to the request of selecting only the upward direction.

Under the assumption that the $x$ depth is independent of $L_\nu$ and $l_{\tau}$, the above integral becomes:

$$\frac{V_{Tot}(E_\tau)}{A} = \left( \frac{l_{\tau}}{1 - \frac{l_{\tau}}{l_{\tau}}} \right) \times \int_0^{\frac{\pi}{2}} \left( e^{-\frac{x}{l_{\tau}CC(\beta)\tau}} - e^{-\frac{x}{l_{\tau}CC(\beta)\tau}} \right) \sin \theta \cos \theta d\theta \quad (2)$$
expressed as a function of the parameter \( \eta = E_\nu/E_{\tau f} \), the fraction of energy transferred from the neutrino to the lepton. At energies greater than \( 10^{15} \) eV, when all mechanisms of energy loss are neglected, \( \eta = E_\nu/E_{\tau f} = E_\nu/E_{\tau i} \approx 1.2 \), meaning that the 80\% of the energy of the incoming neutrino is transferred to the newly born \( \tau \) after the \( \nu - N \) scattering (Gandhi 1996, 1998).

When the energy losses are taken into account, the final \( \tau \) energy \( E_{\tau f} \) is a fraction of the one at its birth, \( E_{\tau i} \). Their ratio \( x_i = E_{\tau f}/E_{\tau i} \) is related to \( \eta \) by the following expression

\[
\eta(E_{\tau f}) = \frac{E_\nu}{E_{\tau f}} = \frac{E_\mu}{E_{\tau f}} \approx \frac{1.2}{x_i(E_{\tau f})}
\]

This ratio defines the fraction of energy of the outgoing \( \tau \) compared to the incoming \( \nu_\tau \).

Once the effective volume is found, we introduce an effective mass defined as

\[
\frac{M_{Tot}}{A} = \rho_{out} \frac{V_{Tot}}{A}
\]

where \( \rho_{out} \) is the density of the outer layer of the Earth crust: \( \rho_{out} = 1.02 \) (water) and 2.65 (rock).

Now we can neglect the severe energy degradation (\( \eta \ll 1 \)) of the HorTaus, considering only those UHE \( \nu_\tau \) that are converted into \( \tau \) within a smaller length \( L_{\tau(\beta)} \) \( (L_{\tau(\beta)}^{-1} \propto \beta + (c_\tau t_{\tau})^{-1} \leq l_{\tau}) \) (see Fargion et al. 2004 for detail). Note that \( \beta \) is the coefficient due to nuclear photoproduction and bremsstrahlung energy losses.

Given that in general \( e^{-\sigma(\theta)/\rho_{CC}} \ll e^{-\sigma(\theta)/\rho_{CC}} \), the second exponential in the integral in Eq. (3) will be also neglected in writing the following equations.

The expression of the effective volume in this most general case becomes

\[
\frac{V_{Tot}(E_{\tau})}{A} = \left( \frac{L_{\tau(\beta)}(E_{\tau})}{1 - \frac{L_{\tau(\beta)}(E_{\tau})}{L_{\nu CC}(\sigma_{\nu CC} n)^{-1}}} \right) \times
\int_0^{2\pi} e^{-\frac{\sigma_{\nu CC}(\sigma_{\nu CC} n)^{-1}}{L_{\nu CC}(\sigma_{\nu CC} n)^{-1}}} \sin \theta \cos \theta d\theta
\]

where the interaction length \( L_{\tau(\beta)} \) (shown in Fig. 8 and compared to \( l_{\tau} \)) guarantees a high energy-coming \( \tau \) even if coming from a thinner Earth crust (see Fargion et al. 2004 for a more detailed discussion of \( L_{\tau(\beta)} \)).

The terrestrial chord, \( D(\theta) \), shown in Fig. 2 is responsible for the \( \nu_\tau \) opacity, and \( L_{\nu} \) is the interaction length for the incoming neutrino in a water equivalent density, where \( L_{\nu CC} = (\sigma_{\nu CC} n)^{-1} \). It should be kept in mind that both \( L_{\nu} \) and \( D(\theta) \),
converted into the water equivalent chord, depend on the number density \( n \) (and the relative matter density \( \rho_r \) of the inner shell tracks). In reality the Earth interior has been idealized as an homogeneous sphere of water of column depth \( D(\theta) \) (see Fig. 2) and the \( \nu_\tau \) interactions are considered for the water density.

We remind that the total neutrino cross section \( \sigma_\nu \) consists of two main component, the charged current and neutral current terms, but the \( \tau \) production depends only on the dominant charged current whose role will appear later in the event number estimate. The interaction lengths \( L_{\tau,\beta}, L_{\nu_{\tau CC}} \), depends on the energy, but one should be careful on the energy meaning. Here we consider an incoming neutrino with energy \( E_\nu \), a prompt \( \tau \) with an energy \( E_\tau \) at its birth place, and a final outgoing \( \tau \) escaping from the Earth with energy \( E_{\tau f} \), after some energy losses inside the crust. The final \( \tau \) shower energy, which is the only observable quantity, is nearly corresponding to the latter value \( E_{\tau f} \), because of the negligible \( \tau \) energy losses in air. However we must be able to infer \( E_\tau \) and the primary neutrino energy, \( E_\nu \), to perform our calculation. The effective volume resulting from Eq. 4 calculated for a detector with a 1 km\(^2\) acceptance area is displayed in Fig. 4.

### 3. Event Rate of Tau air showers for GZK neutrinos with EUSO and Auger

After having introduced the effective volume we can estimate the outcomeing event number rate for EUSO for any given neutrino flux. The consequent event rate for incoming neutrino fluxes may be easily derived by:

\[
\frac{dN_{ee}}{d\Omega dt} = \left( \int \frac{dN_{ee}}{dE_\nu d\Omega dAdE} \sigma_{\nu\tau}(E)dE \right) n\rho_r V_{\text{Tot}}
\]

where \( L_{\nu_{\tau CC}} = (\sigma_{\nu\tau n})^{-1} \), \( \Phi_\nu = \frac{dN_{ee}}{dE_\nu} E_\nu = 5 \cdot 10^{-18} \left( \frac{E_\nu}{10^{18}\text{eV}} \right)^{-\alpha+1} \text{cm}^{-2}\text{sec}^{-1}\text{sr}^{-1} \) describes as a flat spectrum (\( \alpha = 2 \)) most of the GZK neutrino flux and as a linearly increasing spectrum (\( \alpha = 1 \)) the Z-burst model; \( \rho_r \) is the density of the most external layer (either rock or water). The assumption on the flux may be changed at will and the event number will scale linearly according to the model.

In Fig. 5 we show the expected number of event for EUSO where we have included the Earth’s atmosphere and we have used \( L_{\tau,\beta} \), so that we may express the results as a function of the final \( \tau \) lepton energy.

As one can see from Fig. 5 at energy \( E = 10^{19} \) eV the general expected event rate is given by:

\[
N_{ee} = 5 \cdot 10^{-18} \text{cm}^{-2}\text{sec}^{-1}\text{sr}^{-1} \left( \frac{V_{\text{eff}} E_\nu}{L_{\nu_{\tau CC}}} \right) (2\pi \eta_{\text{EusO}} \Delta t) \times \left( \frac{\Phi_\nu E_\nu}{50\text{eV cm}^{-2}\text{sec}^{-1}\text{sr}^{-1}} \right) \eta^{-\alpha} \left( \frac{E_\tau}{10^{19}\text{eV}} \right)^{-\alpha+1}
\]

where \( \eta_{\text{EusO}} \) is the duty cycle fraction of EUSO, \( \eta_{\text{EusO}} \approx 10\% \), \( \Delta t \approx 3 \text{ years} \). Such number of events greatly exceed previous results by at least two orders of magnitude (Bottai et al. 2003) but are comparable, but below more recent estimates (Yoshida et al. 2004).

We have also calculated the number of event rate for the Auger detector (Fargion et al. 2004). The number of events is slightly above the unity at \( E = 10^{19} \) eV (see Fig. 19 in Fargion et al. 2004) for scintillator detection and near 0.1 events/yr for photoluminescent detectors. However at energy as low as \( E = 10^{18} \) eV in GZK model the number of events possibly detectable by the scintillators of Auger increases to 26.3 for a rock layer (for scintillator detectors) and 2.6 events for photofluorecence ones: the most remarkable signature will be a strong azimuthal asymmetry (East-West) toward the high Andes mountain chain. The Andes shield UHECR (toward West) suppressing their horizontal flux. These horizontal showers originated in the atmosphere at hundreds of km, are muon-rich as well as poor in electron pair and gammas and are characterized by a short time of arrival. On the other hand the presence of the mountain ranges at 50 – 100 km from each of the Auger detector will because of the mountain geometry by a numerical fac-
Figure 5. Number of EUSO Event for HorTaus in 3 years record as a function of the outgoing lepton tau \(L_{\tau(\beta)}\) as interaction length), including the finite extension of the horizontal atmospheric layer. At energy \(E_\tau = 10^{19}\) eV, the event number is \(N_{ev} = 3.0 \times \phi_\nu E_\nu/50\) eV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) for the water and \(N_{ev} = 6.0 \times \phi_\nu E_\nu/50\) eV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) for the rock. The resulting number of events has been calculated for an initial GZK neutrino flux: \(\propto E^{-2}\).

Figure 6. Tau decay channels. The probabilities for pion secondaries take into account the contribution of \(K\) mesons originated from \(\tau\) decay [8].

| Decay          | Secondaries | Probability | Air-shower |
|----------------|-------------|-------------|------------|
| \(\tau \rightarrow \pi^\pm \nu_\tau\) | \(\pi^\pm\) | \(\sim 17.4\)% | Unobservable |
| \(\tau \rightarrow \pi^0 \nu_\tau\)   | \(\pi^0\) | \(\sim 17.4\)% | 1 Electromagnetic |
| \(\tau \rightarrow \pi^+ \nu_\tau\)   | \(\pi^+\) | \(\sim 17.4\)% | 1 Hadronic |
| \(\tau \rightarrow \pi^- \bar{\nu}_\tau\) | \(\pi^-\) | \(\sim 17.4\)% | 1 Hadronic |
| \(\tau \rightarrow \pi^0 \bar{\nu}_\tau\) | \(\pi^0\) | \(\sim 17.4\)% | 1 Hadronic |
| \(\tau \rightarrow \pi^+ \nu_\tau\)   | \(\pi^+\) | \(\sim 17.4\)% | 1 Hadronic |
| \(\tau \rightarrow \pi^- \bar{\nu}_\tau\) | \(\pi^-\) | \(\sim 17.4\)% | 1 Hadronic |
| \(\tau \rightarrow \pi^0 \nu_\tau\)   | \(\pi^0\) | \(\sim 17.4\)% | 1 Hadronic |

and we obtain the following expression for the differential rate of events

\[
\frac{dN_{ev}E}{d\Omega d\theta d\phi dt} = \Phi_{\nu_\tau} \eta^{-\alpha} \left( \frac{E_\tau}{E_{\nu_\tau}} \right)^{-\alpha + 1} \rho_\tau \times \\
\left[ 1 - e^{-\frac{E_{\nu_\tau}}{L_{\nu CC}}} \right] \frac{L_{\tau(E_\tau)}}{L_{\nu CC}} e^{-\frac{D_{\tau}}{L_{\nu CC}}} \sin \theta \cos \theta
\]

with \(\eta = 1.2\) and \(E_{\nu_\tau} = 10^{19}\) eV.

We now integrate on the solid angle \(d\Omega\) (half side) we obtain the above formula multiplied by a factor 2\(\pi\).

Given the \(\tau\) number of events we can calculate the rates of \(\mu, e^\pm\) pairs and \(\gamma\), which originates as secondary particles from the \(\tau\) decay (see Fig. 6).

The number of muons is related to the total number of decaying pions and according to Matthews

4. The differential rate of Tau air showers

We introduce now a differential expression of the number of events which allows to calculate the number of events as a function of the angle \(\theta\). We can rewrite the expression of the effective volume given in Eq. 4 as a differential volume for each arrival angle \(\theta\):

\[
\frac{dV}{d\theta d\phi d\Omega dA} = \left[ 1 - e^{-\frac{L_{\nu CC}}{E_{\nu_\tau}}} \right] \times \\
\frac{L_{\tau(E_\tau)}}{1 - \frac{L_{\tau(E_\tau)}}{L_{\nu CC}}} \sin \theta \cos \theta
\]
The differential number of event rate of $\tau$ leptons ($\text{HorTaus}$) for an input GZK neutrino flux. As in previous Figures we are assuming that $\tau$'s are escaping from an Earth outer layer made of rock. Note the discontinuity at $\theta \approx 1$ rad, due to the corresponding inner terrestrial higher density core (see Fig. 2).

$$N_\mu \simeq 3 \cdot 10^5 \left(\frac{E_\tau}{\text{PeV}}\right)^{0.85}$$

$$N_{e^+e^-} \simeq 2 \cdot 10^7 \left(\frac{E_\tau}{\text{PeV}}\right)$$

$$N_\gamma \simeq 10^8 \left(\frac{E_\tau}{\text{PeV}}\right)$$

and we obtain finally

$$\frac{dN_i}{d\theta d\phi dt dA}(E, \theta) = N_i \cdot \frac{dN_{\tau_{ee}}}{dE d\theta d\phi dt dA}$$

We show in Fig. 8 the average differential rate of $\tau$'s and the secondary $\mu^\pm$, $e^\pm$ and $\gamma$ bundles from the decay of $\tau$ leptons. We find that the muon signal at the horizon, related to Earth skimming tau neutrinos is above $10^{-12}$ - $10^{-11}$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$. One should notice that the muonic background produced by atmospheric neutrinos ($\text{CR} \rightarrow \mu^\pm \rightarrow \nu_{\text{atm}} \rightarrow \mu^\pm$) below the horizon approaches at least to the value $\Phi_{\mu_{\text{atm}}} \simeq 2 \cdot 10^{-13}$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$, which is at least one order of magnitude lower than what we have obtained from our calculation for minimal GZK $\nu_\tau$ fluxes (see Fig. 8).

Moreover this muonic shower would have a significant $\gamma$ component, with a high number of photons - $N_\gamma/N_\mu \sim 10^2$ (Cillis & Sciutto 2001; see also Fig. 15 in Cronin 2004) - because of the $\tau$ decay channels into both charged and neutral pions as one can see from Fig. 8.

On the other hand, horizontal UHECRs will not represent a source of contamination for our signal because the horizontal $\gamma$'s produced in the hadronic shower inside the atmosphere would be exponentially suppressed at large slant depth ($X_{\text{max}} \sim 3000$ g cm$^{-2}$) and large zenith angles ($\theta > 70^\circ$) (Cillis & Sciutto 2001). Only $\mu^\pm$ can survive when propagating through the atmosphere at large zenith angles. Such muons would also be source of parasite $\gamma$ signal - due to the...
Figure 9. The differential number of event rate of secondary electron pairs originated from the decay of $\tau$ leptons for an input GZK neutrino flux. As in previous Figures we are assuming that $\tau$’s are escaping from an Earth outer layer made of rock.

$e^\pm$ pair produced in the $\mu^\pm$ decay in flight - but the gamma-to-muon-number ratio would be now approximately $\lesssim 1$.

Therefore, this difference would allow to distinguish gamma-rich HorTaus from common horizontal gamma-poor UHECR events to reveal UHE earth-skimming $\nu_\tau$’s.

For a more precise approach to the calculation of the rate of events one has also to take into account that the number of events varies as a function of the height $h$ at which the observer is located to detect the muonic, electronic and gamma shower. Therefore we introduce an additional factor

$$dN_{\mu ev}(E, \theta, h) = \left(1 - e^{-\frac{h}{R_\tau}}\right) dN_{\mu ev}(E, \theta)$$

(11)

where the parameter $h_s$ that we have introduced as

$$h_s = R_\tau(E_\tau) \sin \theta + \frac{X_{Max}(E_\tau)}{\rho_r} \sin \theta$$

(12)

defines the optimal height where the shower can reach its maximal extension at the corresponding energy $E_\tau$. This is the sum of the height reached by the $\tau$ in the atmosphere before its decay ($R_\tau \sin \theta$), where we have neglected $\tau$ energy losses in the atmosphere, and the altitude reached by the secondary particles of the shower which is related to the parameter $X_{max}$. Note that $R_\tau = 4.9(E_\tau/10^{17} \text{eV})$ km and $X_{max}/\rho_r = 5.7 + 0.46 \ln(E_\tau/10^{17} \text{eV})$ km. Here we have considered the air density $\rho_r = 1.25 \times 10^{-3} \text{ g cm}^{-3}$ constant and equal to the value at the sea level. At low energies ($10^{15} - 10^{16} \text{ eV}$) the second term is dominant and $\rho_r$ can be considered as constant because the $\tau$ lepton travels for less than 1 km before it decays. At higher energy ($10^{17} - 10^{19} \text{ eV}$) the first term is dominant, and we can neglect the way the exact value of $\rho_r$ changes with the altitude.

We show our results in Fig. 11 and Fig. 12 where the secondary $\mu^\pm$ fluxes are described for

Figure 10. The differential number of event rate of secondary $\gamma$’s originated from the decay of $\tau$ leptons for an input GZK neutrino flux. As in previous Figures we are assuming that $\tau$’s are escaping from an Earth outer layer made of rock.
Figure 11. The average differential event rate of secondary muon leptons from HorTaus having assumed \( E_\tau = 10^{17} \) eV and an input GZK-like neutrino flux at different altitudes. Again we are assuming that \( \tau \)'s are escaping from an Earth outer layer made of rock. Note the discontinuity of the angular spectrum due to the inner core of the Earth at \( \theta \simeq 1 \) rad and the asymptotic behaviour for \( h \gg 1 \) km.

two given \( E_\tau \) energies.

5. Conclusions

Horizontal showers from normal hadrons (or gammas) are strongly depleted of their electromagnetic component because of the large slant depth (\( X_{max} > 3 \times 10^4 \) g cm\(^{-2}\)), while horizontal tau air showers are not. Indeed "young" Hor-Taus either of hadronic (67\%) or electromagnetic (33\%) nature (see Fig. 11) at their peak shower activity are expected to have a large \( N_\gamma/N_\mu \) ratio, greater than 10\(^2\) (but with a characteristic energy ratio \( E_\gamma/E_\mu < 10^2 \)). Old horizontal showers would have \( N_\gamma/N_\mu \simeq 1 \). This difference would allow to distinguish and disentangle HorTaus from horizontal UHECR events, even in absence of good angular resolution, opening a new perspective in the UHE neutrino Astronomy. The secondary fluxes of muons and gamma bundles made by incoming GZK neutrino fluxes and their Hor-Taus showers, is well above the noise (by one-two order of magnitude) made by up-going muons, Earth-Skimming trace of atmospheric neutrinos. The neutrino signals at energies much above EeV may be even better probing the expected harder neutrino Z-Burst model spectra [6], [21].

The peak fluences we find in the \( \mu \) and \( \gamma \) component at the horizon (\( \pm 5^\circ \)) will give a signal well above the background produced by atmospheric \( \nu \)’s. We did not discussed the albedo muons whose fluxes measured by Nemo-Decor experiments, \( \phi_\mu \lesssim 10^{-9} \) cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\), are made mostly by single tracks [18]. Because pair (or triple) bundle muons are much rarer (\( \phi_{\mu_{pair}} < 10^{-4} \phi_{\mu_{single}} \approx 10^{-13} \) cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)), the search
and detection of muon bundles by GZK HorTaus at a minimal rate of $10^{-12} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ (over an area of $10^2 \text{ m}^2$) will lead, in a year, to about 30 muons possibly clustered in five to ten multiple bundles. These events will be reinforced by hundreds or thousands of associated collinear gamma flashes. A detector with an area of a few tens or hundreds of square meters pointing to the horizon from the top of a mountain would be able to reveal the GZK $\nu_\tau - \tau$ young showers (Iori, Sergi & Fargion 2004). The characteristics of a prototype twin crown-like array detector to be placed on mountains, balloons, or satellites will be discussed in detail elsewhere. The simultaneous sharp $\gamma$ bundle at $\phi_\gamma \sim 10^{-9} \div 10^{-11} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ and the "burst" of electron pair at $\phi_{e^+e^-} \sim 10^{-9} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ would give evidence of unequivocal $\tau$ signature. It should be remind that the neutrino interaction enhancement by TeV new Physics (as shown in Fig 1 and Appendix C) would produce also an increase of hundreds or thousands time in HorTaus beyond a mountain Chain (like Auger) than standard weak interactions would do. Therefore Auger must soon detect either the Ande Shadows for old UHECR (at zenith angle larger than $85^\circ - 88^\circ$) by their absence as well as young HorTaus productions by the mountain themselves due to New Physics at TeV. In a few years Auger might be even able to observe also GZK neutrinos induced HorTaus at EeV energies (by sure if some technical improvement will be made). EUSO experiment will be able to see at least half a dozen of events of HorTaus mainly enhanced along the Continental Shelves or Mountain edges. To conclude we want to remind that inclined-vertical PeVs $\tau$ air showers (UpTaus) would nearly always be source of $\gamma$ "burst" surviving the atmosphere opacity. These sharp UpTaus (with their companion HorTaus above and near EeVs) might be observed by satellites as brief Terrestrial Gamma Flashes (TGF). Indeed we identified a possible trace of such events in BATSE record (taken during the last decade) of 78 upgoing TGF maybe associated with galactic and extragalactic UHE neutrino sources.

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