The Rise of High Energy Neutrino Astronomy at Horizon

Daniele FARGION* 1,**

Department of Physics, Rome University "La Sapienza", Ple. A. Moro 2, 00185,Rome
1INFN, Rome 1,

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High Energy Neutrino Astronomy energy windows may be ruled by a new Upward and Horizontal Tau Air-Showers (UpTaus, HorTaus) detectors (scintillators and optical arrays) located a few kilometers beyond facing High Mountains Chains, or located above their top or flying on Planes, on Balloons and on Satellites facing downward to the Earth Crust Horizon. While looking downward to the Earth seeking for Upward and Horizontal Tau Air-Showers the same optical detectors may often capture cosmic rays Cherenkov lights reflected or diffused by downward Shower cosmic rays hitting the Earth soil (a sea,a lake, ice lands, desert or ground). These new detectors may be built up as a circular hybrid crown array at high quota facing to horizon in correlation with present largest telescopes, like Magic or Shalon or ASHRA ones, if able to look below the Earth edge. The UpTaus and HorTaus Astronomy at $10^{15}$ eV up to $10^{19}$ eV energy windows may test the largest primary neutrino fluxes in Z-Burst neutrino model needed to solve the GZK puzzle or even the smaller but inevitable GZK neutrino flux secondary of the same GZK cut-off. These HorTus signals might well be observed in future EUSO experiment.

KEYWORDS: Neutrino, Tau, Muon, Air-Shower, Albedo, Horizon, Detector

§1. High Energy Neutrino Astronomy

Ultra High Cosmic Rays, UHECR, diffused in isotropic arrivals at cosmic-like features and their few cluster events correlated to far BL Lac sources, seem to be originated at cosmological distances. Moreover these UHECR events are not clustered at all to any nearby but rarer AGN, QSRs or Known GRBs within the allowable narrow (10–30 Mpc radius) volume defined by the cosmic 2.75 $K^0$ proton drag viscosity (the so called GZK cut-off$^{27,42}$). The recent doublets and triplets clustering found by AGASA seem to favor compact object (as AGN) over more exotic topological relic models. Therefore the missing source AGN within a narrow GZK volume is wondering. A possible remarkable correlation recently shows that most of the UHECR event cluster point toward far away BL Lac sources.$^{26}$ This correlation favors a cosmic origination for UHECRs, well above the near GZK volume. In this frame a relic neutrino mass$^7,36$ $m_\nu \simeq 0.4$ eV (or at least $m_\nu \geq 0.1$) may solve the GZK paradox overcoming the proton opacity: indeed a Z-Shower (or Z-burst) model may explain that the light relic neutrino mass (larger or at least comparable to observed splitting of neutrino masses) should diffuse into huge hot halos whose size is a few tens of Mpc. This dark halo may act as a calorimeter leading to a primary UHE neutrino (at ZeV energies) to hit a relic one neutrino leading to a Z boson production at resonance peak whose relativistic boosted decay contains the nuclear secondaries finally observed on Earth atmosphere as
The light relic neutrinos are the target (the calorimeter) where UHE $\nu$ ejected by distant (above GZK cut-off) sources may hit and convert (via Z boson production and decay) their energy into nuclear UHECR.

These light neutrino masses do not solve the galactic or cosmic dark matter problem but they are well consistent with atmospheric neutrino mass splitting ($\Delta m_\nu \geq 0.05$ eV) and in fine tune with more recent neutrino double beta decay experiment mass claim $m_\nu \simeq 0.4$ eV \textsuperscript{31} . The neutrino mass existence has been also motivated by old and recent solar neutrino oscillation evidences\textsuperscript{25,24,3} and most recent claims by KamLAND \textsuperscript{30} of anti-neutrino disappearance (all in agreement within a Large Mixing Angle neutrino model and $\Delta m_\nu^2 \sim 7 \cdot 10^{-5}$eV$^2$). In this Z-WW Showering for light neutrino mass models large fluxes of UHE $\nu$ are necessary\textsuperscript{10,40,16,23,29} or higher neutrino relic density or better clustering are needed \textsuperscript{16,37} : indeed a heaviest neutrino mass $m_\nu \simeq 1.2 - 2.2$ eV while still being compatible with known bounds (but marginally with more severe WMAP indirect limits), might better gravitationally cluster leading to denser dark local-galactic halos and lower neutrino fluxes \textsuperscript{16,37} . It should remarked that in this scenario $m_\nu \geq$ eVs the main processes leading to UHECR above GZK are mainly the WW-ZZ and the t-channel interactions \textsuperscript{10,16} . It should be noticed that a smaller UHECR flux as low as the HIRES last claims would relax the needed UHE neutrino fluxes $\Phi_\nu$ at energies, $E_\nu \simeq 10^{22}$ eV, at fluence below $\Phi_\nu \leq 10^3$ eV cm$^{-2}$s$^{-1}$sr$^{-1}$, making it well consistent with all known neu-
trino fluence bounds. The neutrino-neutrino cross-sections at boosted incoming neutrino energies in laboratory system are summarized in Fig.1. The consequent showering at all main hadronic and electromagnetic channels are described for a possible degenerated neutrino mass $m_\nu = 0.4eV$ Fig.2 (not consistent with most severe WMAP neutrino mass bounds). The case for lighter neutrino masses comparable to atmospheric ones are considered Fig.3; the case for extremely light and non degenerated neutrino mass splitting is also considered in Fig.4; see also\(^\text{20}\) for description of neutrino densities and detailed decay channel chains. Common critic to the Z-Shower model is the absence in UHECR at $E_{UHECR} \approx 10^{19}$ eV of large detectable $\gamma$ signal (at least at 50\% level of UHECR) contrary to the apparent prediction of dominant $\gamma$ fluxes shown in Fig.2 ,3. However as the neutrino mass goes toward lighter and lighter values it requires wider and wider hot dark neutrino halos. Therefore the widest relic neutrino halo may encompass the same GZK-cut off radius. In this case while UHECR nucleon produced by Z-Shower in GZK volumes will not suffer in its propagation length $R_{UHECR}$ of any severe cut off ($R_{UHECR} \approx 10^3 Mpc$) its $\gamma$ UHECR companion propagation length will be exponentially suppressed ($R_\gamma < 6 Mpc$) by the cosmic radio opacity leading at least to a cubic volume suppression

$$\left(\frac{R_\gamma}{R_{UHECR}}\right)^3 \ll 1$$

This explains the suppression of any large $\gamma$ signal at $E_{UHECR} \approx 10^{19}$ eV in Z-Shower model.

Therefore UHE neutrino in Z-shower model might be an abundant primary of UHECR. Vice-
versa, even ignoring the GZK puzzle and rejecting the Z-Shower model, the same extragalactic UHECR should be at least source during their propagation (by the same photo-nuclear interaction responsible of GZK cut-off) of the so called Greisen GZK neutrino secondaries around \(10^{19}\) eV energies. The independent measure of these neutrino fluxes (either primary as in Z-Burst or secondary as in a naive GZK case) is therefore of great scientific urgency. Because of the small neutrino flux and of the poor weak interactions this highest energy neutrino astronomy call for large detector volumes, much larger than SK or SNO ones for MeV energy solar neutrino. Last three decades were devoted to the study and to the development of a cubic Km\(^3\) underground seeking to track the Cherenkov radiation emitted by relativistic muons (produced by their neutrinos) either in ice (AMANDA) or in water (Baikal, Nestor, Antares).

\section{\(\tau\) Air-Showering for \(\nu\) Astronomy}

A totally New Tau Neutrino Telescope at PeV-EeV energies has been considered more recently\(^{15,11,33}\) based on the use of a mountain as the target and the escaping Tau secondary and its decay in flight as the main amplifier of the UHE neutrino track. UHE \(\nu_\tau\) are abundantly produced by flavour oscillation and mixing from muon (or electron) neutrinos, because of the large galactic and cosmic distances respect to the neutrino oscillation ones (for already known neutrino mass splitting)\(^{11}\). Therefore the UHE Neutrino may interact on Mountain Chains or Earth Crust leading to UHE Tau whose decay in flight and consequent air-shower may be observed along or near the wide shower cone. This Astronomy is based on \(\nu_\tau,\overline{\nu_\tau}\) interactions at PeV-GZKs (\(E_{\nu_\tau} \simeq 10^{15} - 10^{19}\) eV) energies as well as on \(\overline{\nu_e}\) interactions (in resonance with \(W^-\) gauge boson mass at 6.3 PeV), hitting common electron in the mountain rock. The \(W^-\) decay branching ratio contains within 10\% The UHE \(\overline{\nu_\tau}\) and \(\tau\) birth whose propagation and escape from the mountain as well as its decay in flight may come as the source of an amazing Horizontal Showering from the Andes mountain Chain toward AUGER\(^{15,11,6}\) or by Horizontal (so called Earth-Skimming\(^{15,11,22}\)) showers flashing upward to new Mountain Observatory or present and future Gamma Detectors in high altitude (mountain, Balloon, Airplanes) or orbit Space\(^{13,14,11}\). In this frame Tau upward Showers (UPTAUs) may have already blaze the most sensible and celebrated
Fig. 7. UPTAU’s (lower bound on the center) and HORTAU’s (right parabolic curves) sensitivity at different observer heights h (2.5, 25, 500km) looking at horizon toward Earth seeking upward Tau Air-Shower adapted over a present neutrino flux estimate in Z-Showers model scenario for light (0.4 – 0.84 eV) neutrino masses $m_\nu$; two corresponding density contrast for relic light neutrino masses has been assumed; the lower parabolic bound thresholds are at different operation height, in Horizontal (Crown) Detector facing toward most distant horizon edge; these limits are fine tuned (as discussed in the text) in order to receive Tau in flight and its Shower in the vicinity of the detector; we are assuming a duration of data records of a decade comparable to the BATSE record data. The parabolic bounds on the EeV energy range in the right sides are nearly un-screened by the Earth opacity while the corresponding UPTAU bounds in the center below suffer both of Earth opacity as well as of a consequent shorter Tau interaction length in Earth Crust, that has been taken into account.

Fig. 8. Neutrino Flux derived by BATSE Terrestrial Gamma Flashes assuming them as $\gamma$ secondaries of upward Tau Air-shower. These fluxes are estimated using the data from Terrestrial Gamma Flash (1991-2000) normalized during their most active trigger and TGF hard activities. The UPTAU and HORTAU rate are normalized assuming that the events at geocenter angle above 50° might be of HORTAU nature.

Fig. 9. Lepton $\tau$ (and $\mu$) Interaction Lengths for different matter densities: $R_{\tau}$ is the free $\tau$ length, $R_{\tau}^{New}$ is the New Physics TeV Gravity interaction range at corresponding densities, $R_{\tau}^{New} \rho$ is the combined $\tau$ Ranges keeping care of all known interactions and lifetime and mainly the photo-nuclear interaction. There are two slightly different split curves (for each density) by two comparable approximations in the interaction laws. Note also the neutrino interaction lengths above lines $R_{Weak}= L_{\nu}$ due to the electro-weak interactions at corresponding densities.

GRO Observatory, on Space for nearly a decade, leading to a rare amazing $\gamma$ showers named as Up-going Terrestrial Gamma Flashes, TGF, by BATSE experiment\textsuperscript{11,20}. Also Horizontal Tau Showers (HORTAU’s), at higher energies may hit the satellite from the Horizon. Indeed it has been noticed possibly early signals in correlation with EeV galactic anisotropy discovered by AGASA and the EGRET galactic plane. Their deduced fluxes\textsuperscript{20} are just at the edge of present AMANDA II thresholds. Therefore AMANDA II may already confirm (within a few year) these UPTAU and HORTAU fluxes and their sources.

§3. EUSO experiment for UHE GZK $\nu$

There is more and more expectation also on new space experiment like EUSO outcoming project. This experiment, while monitoring at dark, downward to the Earth, a
wide atmosphere layers, may discover, among common downward Ultra High Energy Cosmic Rays, UHECR showers, also first High Energy Neutrino-Induced Showers. These events are either originated in Air (EUSO Field of View) or within a widest Earth Crust ring crown leading to ultra high energy Tau whose decay in flight produce up-ward and horizontal showers. Upward PeVs neutrinos, born on air and more probably within a thin Earth Crust layer, may shower rarely and blaze to the EUSO detectors. Other higher energy neutrino may cross horizontally hitting either the Earth Atmosphere or the Earth Crust: most of those vertical downward neutrinos, interacting on air, should be drown in the dominant noise of downward UHECR showers. The effective target Masses originating HORTAUs seen by EUSO may reach (on sea), for most realistic regime (at energy $E_{\nu_{\tau}} = 1.2 \cdot 10^{19}$ eV) a huge ring volume $\simeq 2360 \text{ km}^3$. The consequent HORTAUS event rate (even at 10% EUSO duty cycle lifetime) may well test the expected Z-Burst models by at least a hundred of yearly events. However, even rarest but inescapable GZK neutrinos (secondary of photopion production of observed cosmic UHECR) should be discovered in a dozen of horizontal upward shower events; in this view an extension of EUSO detectability up to $\sim E_{\nu} \geq 10^{19}$eV threshold is mandatory. A wider collecting EUSO telescope (3m diameter) should be considered. This new Neutrino $\tau$ detector will be (at least) complementary to present and future, lower energy, $\nu$ underground $\text{km}^3$ telescope projects (from AMANDA, Baikal, ANTARES, NESTOR, NEMO, IceCube). In particular Horizontal Tau Air shower may be naturally originated by UHE $\nu_{\tau}$ at GZK energies crossing the thin Earth Crust at the Horizon showering far and high in the atmosphere \((11)\) \((13)\) \((14)\) \((6)\) \((22)\) .

Let us first consider the last kind of Upward $\tau$ signals due to their interaction in Air or in Earth Crust (UPTAUs). The Earth opacity will filter mainly $10^{14} \div 10^{16}$eV upward events \((34)\) \((32)\) \((2)\) \((8)\) \((11)\) ; therefore only the direct $\nu$ shower in air or the UPTAUs around 3 PeVs will be able to flash toward EUSO in a narrow beam \((2.5 \cdot 10^{-5} \text{ solid angle})\) jet blazing apparently at $10^{19} \div 10^{20}$eV energy. The shower will be opened in a fan like shape and it will emerge from the Earth atmosphere spread as a triplet or multi-dot signal aligned orthogonal to local terrestrial magnetic field.

![Fig. 10. Upward Neutrino Air-Shower and Upward Tau Air-shower, UPTAUs, Gamma and Cosmic Rays Fluence Thresholds and bounds in different energy windows for different past and future detectors. The UPTAUs threshold for EUSO has been estimated for a three year experiment lifetime. BATSE recording limit is also shown from height $h = 500km$ and for ten year record. Competitive experiment are also shown as well as the Z-Shower expected spectra in light neutrino mass values $m_{\nu} = 0.4, 0.04 \text{ eV}$.](image)

This rare multi-dot polarization of the outcoming shower will define a characteristic signature easily to be revealed. However the effective observed air mass by EUSO is not 10% (because duty cycle) of the inspected air vol-
ume $\sim 150 km^3$, but because of the narrow blazing shower cone it corresponds to only to $3.72 \cdot 10^{-3} km^3$. The target volume increases for upward neutrino Tau interacting vertically in Earth Crust in last matter layer (either rock or water), making upward relativistic $\simeq 3 PeV s$ $\tau$ whose decay in air born finally an UPTAUs; in this case the effective target mass is (for water or rock) respectively $5.5 \cdot 10^{-2} km^3$ or $1.5 \cdot 10^{-1} km^3$.

The characteristic neutrino interaction are partially summarized in Fig.9. The consequent $\tau$ and $\mu$ interactions length are also displayed. These volume are not extreme. The consequent foreseen thresholds for UPTAUs are summarized for 3 EUSO years of data recording in Fig.10. The UPTAUs signal is nearly 15 times larger than the Air-Induced Upward $\nu$ Shower hitting Air. A more detailed analysis may show an additional factor three (due to the neutrino flavours) in favor of Air-Induced Showers, but the more transparent role of PeV multi-generating upward $\nu_\tau$ while crossing the Earth, makes the result summarized in Fig.10. The much wider acceptance of BATSE respect EUSO and the consequent better threshold (in BATSE) is due to the wider angle view of the gamma detector, the absence of any suppression factor as in EUSO duty cycle, as well as the 10 (for BATSE) over 3 (for EUSO) years assumed of record life-time. Any minimal neutrino fluence $\Phi_{\nu_\tau}$ of PeVs energetic neutrino: $\Phi_{\nu_\tau} \geq 10^2 eV cm^{-2} s^{-1}$ might be detectable by EUSO.

3.1 Downward and Horizontal UHECRs in EUSO

Let us now briefly reconsider the nature of common Ultra High Cosmic Rays (UHECR) showers. Their rate will offer a useful test for any additional UHE neutrino signals. Let us assume for sake of simplicity a characteristic opening angle of EUSO telescope of 30° and a nominal satellite height of 400 km, leading to an approximate atmosphere area under inspection of $\Phi_{\nu_\tau} \sim 1.5 \cdot 10^5 km^2$. Let us discuss the UHECR shower: It has been estimated (and it is easy to verify) a $\sim 2 \cdot 10^3$ event/year rate above $3 \cdot 10^{19}$ eV. Among these "GZK" UHECR (either proton, nuclei or $\gamma$) nearly $7.45\% \approx 150$ event/year will shower in Air Horizontally with no Cherenkov hit on the ground. The critical angle $6.7^\circ$ corresponding to $7.45\%$ of all the events, is derived from first interacting quota (here assumed for Horizontal Hadronic Shower near 44 km following(11) 13)14) . Indeed the corresponding horizontal edge critical angle $\theta_h = 6.7^\circ$ below the horizon ($\pi/2$) is found (for an interacting height $h$ near 44 km): 

$$\theta_h = \arccos \left( \frac{R_\oplus}{(R_\oplus + h)} \right) \simeq 1^\circ \sqrt{\frac{h_1}{km}}$$

Fig. 11. A schematic Horizontal High Altitude Shower (HIAS) suffering a geo-magnetic bending at high quota ($\sim 44 km$). These expected events may mimic HORTAUs. The Shower may point to a satellite. The HIAS Showers is open and forked in five (or at least two-three main component): ($e^+, e^-, \mu^+, \mu^-, \gamma$, or just a positive-negative twin jet ); these multi-finger tails may be recognized by their split tails.

These Horizontal High Altitude Showers (HIAS) 13) 14), will be able to define a new
Fig. 12. Neutrino, Gamma and Cosmic Rays Fluence Thresholds and bounds in different energy windows. The Cosmic Rays Fluence threshold for EUSO has been estimated for a three year experiment lifetime. The paraboloid bound shape threshold may differ upon the EUSO optics and acceptance. Competitive experiment are also shown as well as the Z-Shower expected spectra in light mass values.

Fig. 13. EUSO thresholds for Horizontal and Vertical Downward Neutrino Air induced shower over other $\gamma$, $\nu$ and Cosmic Rays (C.R.) Fluence and bounds. The Fluence threshold for EUSO has been estimated for a three year experiment lifetime. Competitive experiments are also shown as well as the Z-Shower expected spectra in light neutrino mass values ($m_{\nu} = 0.04, 0.4$ eV).

peculiar showering, mostly very long (hundred kms) and bent and forked (by few or several degrees) by local geo-magnetic fields. The total UHECR above $3 \cdot 10^{19}$ eV will be $\sim 6000$ UHECR and $\sim 450$ Horizontal Shower within 3 years; these latter horizontal signals are relevant because they may mimic Horizontal induced $\nu$ Air-Shower, but mainly at high quota ($\geq 30 - 40km$) and down-ward. On the contrary UHE neutrino tau showering, HORTAUs, to be discussed later, are also at high quota ($\geq 23km$), but upward-horizontal. Their outcoming angle will be ($\geq 0.2^o - 3^o$) upward. Therefore a good angular ($\leq 0.2^o - 0.1^o$) resolution to distinguish between the two signal will be a key discriminator. While Horizontal UHECR are an important piece of evidence in the UHECR calibration and its GZK study, at the same time they are a severe back-ground noise competitive with Horizontal-Vertical GZK Neutrino Showers originated in Air, to be discussed below. However Horizontal-downward UHECR are not confused with upward Horizontal HORTAUs by UHE neutrinos to be summarized in last section. Note that Air-Induced Horizontal UHE neutrino as well as all down-ward Air-Induced UHE $\nu$ will shower mainly at lower altitudes ($\leq 10km$); however they are respectively only a small ($\leq 2\%, \leq 8\%$) fraction than HORTAUs showers to be discussed in the following. An additional factor 3 due to their three flavour over $\tau$ unique one may lead to respectively ($\leq 6\%, \leq 24\%$) of all HORTAUs events: a contribute ratio that may be in principle an useful test to study the balanced neutrino flavour mixing.
3.2 Air Induced UHE $\nu$ Shower in EUSO

UHE $\nu$ may hit an air nuclei and shower vertically or horizontally or more rarely nearly up-ward: its trace maybe observable by EUSO preferentially in inclined or horizontal case. Indeed Vertical Down-ward ($\theta \leq 60^o$) neutrino induced Air Shower occur mainly at lowest quota and they will only partially shower their UHE $\nu$ energy because of the small slant depth ($\leq 10^3 gcm^{-2}$) in most vertical down-ward UHE $\nu$ shower. Therefore the observed EUSO air mass (1500 $km^3$, corresponding to a $\sim 150$ $km^3$ for 10% EUSO record time) is only ideally the UHE neutrino calorimeter. Indeed inclined $\sim \theta \geq 60^o$ and horizontal Air-Shower ($\sim \theta \geq 83^o$) (induced by GZK UHE neutrino) may reach their maximum output and their event maybe observed ; therefore only a small fraction ($\sim 30\%$ corresponding to $\sim 50$ $km^3$ mass-water volume for EUSO observation) of vertical downward UHE neutrino may be seen by EUSO. This signal may be somehow hidden or masked by the more common down-ward UHECR showers. The key reading signature will be the shower height origination: ($\geq 40km$) for most downward-horizontal UHECR,($\leq 10km$) for most inclined-horizontal Air UHE $\nu$ Induced Shower. A corresponding smaller fraction ($\sim 7.45\%$) of totally Horizontal UHE neutrino Air shower, orphan of their final Cherenkov flash, in competition with the horizontal UHECR, may be also clearly observed: their observable mass is only $V_{Air-\nu-Hor} \sim 11.1$ $km^3$ for EUSO observation duty-cycle. A more rare, but spectacular, double $\nu_\tau-\tau$ bang in Air (comparable in principle to the PeVs expected ”double bang” in water$^{35}$) may be exciting, but very difficult to be observed.

The EUSO effective calorimeter mass for such Horizontal event is only 10% of the UHE $\nu$ Horizontal ones ($\sim 1.1$ $km^3$); therefore its event rate is already almost excluded needing a too high neutrino fluxes (see$^{20}$); indeed it should be also noted that the EUSO energy threshold ($\geq 3 \cdot 10^{19}$eV) imply such a very large $\tau$ Lorents boost distance; such large $\tau$ track exceed (by more than a factor three) the EUSO disk Area diameter ($\sim 450km$); therefore the expected Double Bang Air-Horizontal-Induced $\nu$ Shower thresholds are suppressed by a corresponding factor. More abundant single event Air-Induced $\nu$ Shower (Vertical or Horizontal) are facing different Air volumes and quite different visibility. It must be taken into account an additional factor three (for the event rate) (because of three light neutrino states) in the Air-Induced $\nu$ Shower arrival flux respect to incoming $\nu_\tau$ (and $\bar{\nu}_\tau$) in UPTAUs and HORTAUs, making the Air target not totally a negligible calorimeter. The role of air Air-Shower will be discussed elsewhere.

There are also a sub-category of $\nu_\tau-\tau$ ”double bang” due to a first horizontal UHE $\nu_\tau$ charged current interaction in air nuclei (the first bang) that is lost from the EUSO view; their UHE secondary $\tau$ fly and decay leading to a Second Air-Induced Horizontal Shower, within the EUSO disk area. Therefore the total Air-Induced Horizontal Shower (for all 3 flavours and the additional $\tau$ decay in flight) are summarized and considered in Fig. 13. The most relevant UHE neutrino signal, as discussed below,
§4. GZK $\nu_\tau - \tau$ Horizontal Showers in EUSO

As already mentioned, the UHE $\nu$ astronomy may be greatly amplified by $\nu_\tau$ appearance via flavour mixing and oscillations. The consequent scattering of $\nu_\tau$ on the Mountains or into the Earth Crust may lead to Horizontal Tau Air-showers: HORTAUs (or Earth Skimming Showers$^{13}$ $^{14}$ $^{11}$ $^{22}$) . Indeed UHE $\nu_\tau$ may skip below the Earth and escape as $\tau$ and finally decay in flight, within air atmosphere, as well as inside the Area of view of EUSO, as shown in Fig.14 below.

4.1 UPTAUs and HORTAUs effective Volumes

Any UHE-GZK Tau Air Shower induced event is approximately born within a wide ring (whose radiuses extend between $R \geq 300$ and $R \leq 800$ km from the EUSO Area center).

\[ V_{eff} \approx \frac{\pi}{A_\oplus} \int_0^{\frac{\pi}{2}} \frac{(2 \pi R_\oplus \cos \theta) l_\tau \sin \theta}{4 \pi R_\oplus^2} \cdot e^{-\frac{2 R_\oplus \sin \theta}{L_{\nu_\tau}}} \cdot R_\oplus \, d\theta = \frac{1}{2} \left( \frac{L_{\nu_\tau}}{2 R_\oplus} \right)^2 l_\tau \int_0^{\frac{2 R_\oplus}{L_{\nu_\tau}}} e^{-t} \, dt (1) \]

Where $V_{eff}$ is the effective volume where Ultra High Energy neutrino interact while hitting the Earth and lead to escaping UHE Tau: this volume encompass a wide crown belt, due to the cross-section of neutrino Earth skimming along a ring of variable radius, $R_\oplus \cos \theta$, and a corresponding skin crown of variable depth $l_\tau$. $A_\oplus$ is
the total terrestrial area, $l_\tau$ is the tau interaction length, $L_{\nu_\tau}$ is the Ultra High Energy Neutrino tau interaction (charged current) in matter. The resulting detectable volume from EUSO becomes, (see the combined effective volume in Fig. 16):

$$V_{\text{eff}} = \frac{1}{2} A_{Euso} \left( 1 - e^{-\frac{L_{\nu_\tau}}{2 R_\oplus}} \right)^2 \cdot \frac{L_{\nu_\tau}}{2 R_\oplus} \left[ 1 - e^{-2 \frac{R_\oplus}{L_{\nu_\tau}}} \frac{L_{\nu_\tau}}{2 R_\oplus} \right]$$ (2)

The above effective volume should be considered for any given neutrino flux to estimate the outcoming EUSO event number. These general expression will be plot assuming a minima GZK neutrino flux $\phi_\nu$ just comparable to observed UHECR one $\phi_{UHECR} \simeq 3 \cdot 10^{-18} cm^{-2}s^{-1}sr^{-1}$ at the same energy ($E_\nu = E_{UHECR} \simeq 10^{19} eV$). This assumption may changed at will (model dependent) but the event number will scale linearly accordingly to any incoming neutrino flux model. From here we may estimate the event rate in EUSO by a simple extension:

$$N_{\text{eventi}} = \Phi_\nu 4 \pi \eta_{Euso} \Delta t \left( \frac{V_{\text{eff}}}{L_{\nu_\tau}} \right)$$

Where $\eta_{Euso}$ is the duty cycle fraction of EUSO, $\eta_{Euso} \simeq 10\%$, $\Delta t \simeq 3$ years and $L_{\nu}$ has been defined in Fig.9.

$$N_{\text{eventi}} = \Phi_\nu A_{Euso} \left( \frac{1}{2} \cdot 4 \pi \eta_{Euso} \right) \Delta t \cdot \left( 1 - e^{-\frac{L_{\nu_\tau}}{2 R_\oplus}} \right) \left( \frac{L_{\nu_\tau}}{2 R_\oplus} \right)^2 \cdot \left[ 1 - e^{-2 \frac{R_\oplus}{L_{\nu_\tau}}} \frac{L_{\nu_\tau}}{2 R_\oplus} \right]$$ (3)

The term $\left( 1 - e^{-\frac{L_{\nu_\tau}}{c \tau \gamma \gamma}} \right)$ takes into account the limit of the air atmosphere on Earth which is basically at height $h \simeq 23km$ and at a corresponding distance $L_0 \simeq 600km$. It should be remind that all these event number curves for EUSO are already suppressed by a factor $\eta_{Euso} \simeq 0.1$ due to minimal EUSO duty cycle.

The same effective Volume , under the assumptions of an incoming neutrino energy $E_{\nu_\tau} = 4E_\tau$ and under the assumption that the outcoming Tau energy leading to a Shower is $E_\tau = 1.5E_{\text{shower}}$ corresponds, in water at $E_\tau = 10^{19} eV$, to $V_{\text{eff}} = 1.13 \cdot 10^3 km^3$; the corresponding event number is $N_{\text{ev}} = 13.4$. See Fig.16.

As it is manifest from the above curve the maximal event numbers takes place at EeV energies. Therefore from here we derived the primary interest for EUSO to seek lowest threshold.

4.2 UPTAUs-HORTAUs unified volume

The above expression for the horizontal tau air-shower contains , at lowest energies, the UPTAUs case. Indeed it is possible to see that the same above effective volume at lowest energies simplify and reduces to:

$$V_{\text{eff}} = \frac{1}{2} A_{Euso} \left( 1 - e^{-\frac{L_{\nu_\tau}}{2 R_\oplus}} \right) l_\tau$$

Because one observes the Earth only from one side the Area factor in eq. 1 should be $A_\oplus = 2 \pi R_\oplus^2$ and therefore the half in above formula may be dropped and the final result is just the common expression $V_{\text{eff}} = A_{Euso} l_\tau$.

4.3 Partially, Fully contained events in EUSO

The HORTAUs are very long showers. Their lenght may exceed two hundred kilometers. This trace may be larger than the EUSO radius of Field of View. Therefore there may be
Fig. 16. Effective Volume of EUSO Event for UPTAUs and HORTAUs assuming a GZK neutrino flux $dN/\Sigma dE dA d\Omega = 3 \cdot 10^{-18} cm^{-2} s^{-1} sr^{-1}$, corresponding to fluence $\Phi_\nu = 30eV cm^{-2} s^{-1} sr^{-1}$. The effective Volume is for all Upcoming Upward-Horizontal Tau Air-Shower, contained within the EUSO area nearly at 25 km altitude where it may still shower. This Volume is estimated under the assumptions of an incoming neutrino energy $E_\nu = 4E_\tau$ and under the assumption that the outcoming Tau energy is leading to a Shower is $E_\tau = 2E_{\text{Shower}}$

Fig. 17. Number of EUSO Event for HORTAUs in 3 years record assuming a GZK neutrino flux $dN/\Sigma dE dA d\Omega = 3 \cdot 10^{-18} cm^{-2} s^{-1} sr^{-1}$. The incoming neutrino has an energy 4 larger than the outcoming Tau; this born Tau has an energy 2 times the final Tau Air-Shower end energy.

Fig. 18. The Number of Events for HORTAUs and UPTAUs in 3 years record for square km$^2$ area assuming a given flat GZK neutrino fluence $\Phi_\nu = 30eV cm^{-2} s^{-1} sr^{-1}$ in all energies. This value corresponds to a GZK minimal flux and a minimal UHE neutrino fluence comparable to the Waxman-Bachall limit. The assumed incoming neutrino has an energy 4 larger than the outcoming Tau; this born Tau has an energy 2 times the final Tau Air-Shower end energy. Note however that at lowest energies the present approximation should slightly deviate because the total exact Earth opacity has been a little underestimated but the $\nu_\tau - \tau$ regeneration has been totally neglected. Nevertheless this estimate in present form is a realistic approximation in the central energy window considered.

The area of their origination, four times larger than EUSO field of view, will be mostly outside the same EUSO area. Their total number count will double the event rate $N_{\nu \tau}$ (and the corresponding $V_{\text{eff}}$) of HORTAUs. The additional crossing event will make additional events (a small fraction) of the effective volume of HORTAUs at $10^{19}eV$ the most rich neutrino signal few times larger the Air induced events. The
same doubling will apply only to UHECR horizontal shower while the downward Ultra High Energy Neutrino will not share this phenomena (out of those $\simeq 6\%$ of the Horizontal Air Neutrino Shower).

§5. Conclusions

The Neutrino Astronomy may be widely discovered by Upward and Horizontal $\tau$ Air-Shower. The Tau neutrinos, born abundantly by flavour mixing will probe such Astronomy above PeVs up to EeVs energies, where astrophysics rule over atmospheric neutrino noise. The same UHE $\overline{\nu}_e$ at $E_{\nu_e} = \frac{M_{\nu_e^2}}{2m_e} \simeq 6.3PeV$ must be a peculiar neutrino astronomy born beyond Mountain Chains with its very distinctive signature. This ground $\tau$ Air-Shower astronomy may test (by shower distance correlation) very deeply the $\nu_e$ versus $\nu_\tau$ fluxes. Past detectors as GRO BATSE experiment might already found some direct signals of such rare UPTAUs or HORTAUs; indeed their observed Terrestrial Gamma Flash event rate translated into a neutrino induced upward shower (see Fig.8) leads to a most probable flux both at PeVs energies just at a level comparable to most recent AMANDA threshold sensitivity: for horizontal TGF events at $10^{19}$ eV windows, these signals just fit the Z-Burst model needed fluence (for neutrino at $0.04 - 0.4$ eV masses).

Future EUSO telescope detector, if little enlarged will easily probe even the smallest, but necessary Neutrino GZK fluxes with clear sensitivity (see Fig. 19,20). We therefore expect that a serial of experiment will soon turn toward this last and neglected, but most promising.
Energy Neutrino Tau Astronomy searching for GZK or Z-Showers neutrino signatures just beyond the horizon.

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