NEUTRINO ASTRONOMY
AND COSMIC RAYS SPECTROSCOPY
AT HORIZONS\textsuperscript{a}

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ABSTRACT
Air-showering physics may rise in next years at horizon, offering at different angles and altitudes a fine tuned and a filtered Cosmic Rays astrophysics and a Neutrino induced air-showering astronomy; this is possible because of neutrino masses, their mixing and the consequent replenishment of rarest tau flavor during neutrino flight into interstellar spaces. Earth edges and its sharp shadows is a huge detector volume for UHE neutrino and a noise-free screen mostly for tau air-showers (as well PeVs anti-neutrino electron air interactions). Satellite BATSE might, in last decade, already recorded such Upgoing tau airshowers as Terrestrial Gamma Flashes. ASHRA in Hawaii and CRNTN in Utah are tracking such fluorescence lights, while other projects on Crown array detectors for Cherenkov signals on mountains, on balloons and satellites are being elaborated and tested to Tau Air-Showers neutrinos: AUGER, facing the Ande edges, ARGO located within a deep valley may both test inclined showers from the mountains; MILAGRO (and MILAGRITO) on the top mountain may all both be triggered by horizontal up-going muon bundles from the Earth edges; HIRES and better AUGER detectors, linking twin telescopes or array scintillators along their telescope axis may test horizontal Cerenkov blazing photons as well as nearby Tau airshowers. MAGIC (or Veritas or Shalon) Telescopes pointing downward to terrestrial ground acts, for EeV Tau neutrino air-showers astronomy, as a massive tens of km$^3$ water equivalent detector, making it at present the most powerful dedicated neutrino telescope. MAGIC facing the sea edges must also reveal mirrored downward UHECR Air-showers Cherenkov flashes. Magic-crown systems may lead to largest neutrino detectors in near future. They maybe located on top mountains, on planes or balloons and in satellite arrays. Amplified Tau-airshower at horizons may well open a blazing windows, at PeV-EeV energy, to Neutrino Astronomy.

1. Why Horizontal Air-shower may be disentangled at high altitudes?

This introductive article offer the minimum of mathematical equation and the wider view of the title program; I will use the image communicative power to describe at least in qualitative way the multi-face opportunity of the novel theme of horizontal air-showering from Earth and Space. Indeed while most of low energy CR ($E_{CR} \sim 10^9 - 10^{12} eV$) are observable from space, downward higher ones ($E_{CR} \geq 10^{12} - 10^{15} eV$) are deduced by their secondaries in air-showers on Earth ground. However

\textsuperscript{a}Invited talk at the III International Workshop NO-VE in Venice,Italy, February 9, 2006.
most of the vertical downward air shower are absorbed at high altitude (5 ÷ 10 km), because their maximal shower slant depths occurs (for instance at the PeV energy at $X_{max} \simeq 500g./cm^2$), in half of the way to ground. Only tiny traces of muon bundles or Cerenkov flashes are recordable at high altitude (balloon or mountain) or on array at sea level. However in the vertical axis the opening angle and its consequent shower area (0.1 ÷ 1km$^2$) is quite limited and a few days balloon trip record time often is unable to catch most rare energetic events. On the contrary horizontal air-showers observed along the atmosphere are widely spread by their longer distances (300 ÷ 500 km) into widest areas ($10^1 ÷ 10^2 km^2$). For this reason observing at different altitude and angle of view the horizontal air-shower may amplify its area and its intensity leading to a filter of air-shower primary energy, composition and cross-section. There is a wide net of shower component to be correlated offering, in principle, the possibility to disentangle the primary energy even by its partial and limited lateral distribution data. Their arrival angle, the consequent slant depth, the secondary arrival timing, the electromagnetic ($e^+, e^-, \gamma$) components and their ratios, the muon component content ($\mu^+, \mu^-$), the net charge presence (due to geomagnetic shower bending), the pion and nucleon traces ($p, \bar{p}, n, \bar{n}$), the Cerenkov signature and the photo fluorescence signal could trace overall the shower nature and geometry. We now remind that vertical showers (as PeV event in figure) leave only a tiny muon secondary on the ground, less than 0.1% of the primary energy. The horizontal ones, observed while skimming the air atmosphere, offer in principle a much elongated but rich air-shower, at high altitude (10 ÷ 40 km.), a narrower jet cone, but a final wider area (≃ km$^2$, 100 · km$^2$) of spread secondaries, contrary to vertical showers. Their valuable study may calibrate the detector for a more exciting horizontal air-showers: the up-going ones induced by Neutrino interactions in air or Earth (Tau Air-Showers or Earth Skimming Neutrinos).

1.1. The horizontal CR showering spectroscopy: a new view

The quantity of information encoded in high altitude air-shower is so wide that I cannot summarize it in one single even introductive paper. There are at each altitude and air density,a cosmic ray energy and composition in novel condition and morphology making a new exciting CR showering spectroscopy. For instance at near a hundred km. altitudes, low energy solar wind rays may interact by atomic cross-sections lightening auroras in polar nights; at lower altitudes (50−60 km.) low energy (GeV-TeV$s$) cosmic rays at horizons are crowding into thin jet-showers population (tens km length), while at lower altitudes (near 40 km.) PeV horizontal air-showers are expanding at maximum size in extreme (few hundred km. long) thin beamed air-showers. Parallel to them even more rarer and higher energetic C.R. are showering at maximal length (few hundred km. long) often splitting by geomagnetic fields into twin forked jets. These CR viewing at different quotas could be imagined, in brief, as
Figure 1: The very different High Altitude air-shower morphology at horizons, whose sizes are tens-hundred time longer, and whose Cherenkov beaming are thinner (at $35\text{km}$ altitude as small angle beam as $0.1^\circ$) than vertical ones ($1.4^\circ$) because of a much smaller (up to $0.01$ times respect sea level) air density. Along some directions (mostly East-West) they are bent and forked in twin beams by geomagnetic fields. These air-shower profiles (not in real-scale) are shown for prompt evaluation, in comparison with the moon size (whose diameter at Earth horizons from Space Station is as wide as $20$ km.). Also a vertical PeV C.R. air-shower, at sea level is playing a role of a meter. These air-shower shapes are shown at right angle to the observer. When beamed in axis to the observer their flash may blaze by Cherenkov lights, either as an unique or often as a twin (opposite charge) or a triple (positive-negative neutral components of the shower) light spots. The twin spots are as large as tens kilometers each one far from the other; the separation occurs because of the “polarized” splitting of the terrestrial magnetic fields.

See ref.\textsuperscript{12}
a tuning filter for cosmic rays which may compete and calibrate, above the horizons, with a very different up-going air showering mostly triggered by $\bar{\nu}_e + e \rightarrow W^-$ and $\nu_\tau + N \rightarrow \tau + N$, $\bar{\nu}_\tau + N \rightarrow \bar{\tau} + N$ interactions\(^{21}\). More exotic (but allowable even if difficult to reveal) SUSY ultra-high C.R. traces, energetic neutralinos $\chi$, see\(^7\), may interact with air and electrons making right-handed s-electron resonances, leading to unique electromagnetic air-showers $e + \chi \rightarrow \tilde{e} \rightarrow e + \chi$, see\(^7\), similar some-how to Glashow (mostly hadronic) neutrino-electron resonant showers. These neutrinos air shower at horizons is very competitive with the conventional muon track $\nu$ astronomy searched in underground detectors\(^1\). The main differences between $\mu$ (and $\tau$) underground (versus air showering lepton) neutrino telescope is based on four opposite facts:

1. Muons are much more penetrating (up to tens PeVs) than tau but at EeV regime (and above) the opposite is true: tau exceed muon tracks.

2. High energy Tau might be well revealed by sampling a few of their unique amplified air shower, (millions,billions) secondaries, once their up-going arrival direction is well recorded. Each downward high energy muon (in km\(^3\) detector) should be traced for a long path and disentangled by its energy and more over by its eventual atmospheric or astrophysics nature\(^1\).

3. Tau is unstable and decays in air flight, while $\mu$ is, since PeV up EeV energy, extremely stable on any terrestrial size scales. So $\mu$ PeV-EeV air shower is not common in air even if partial (1\%) atmospheric muon showering may shine above the horizons, possibly to be tested and verified.

4. Neutrino-induced muons downward are polluted, even in underground detector, by million times more atmospheric muons. Because of the long string geometry in AMANDA and most detectors, up-going verticals muons bundles are the best view of water or ice underground arrays. Up-going muon above tens TeV (where astrophysical neutrino astronomy should overcome atmospheric neutrino noises) are more and more opaque to the Earth diameter. Therefore because the Earth opacity the horizons (whose cord are small enough , a few hundred km.) is the best direction to search for PeV-EeV neutrinos either in underground detectors as well as in air .

In conclusion above tens-hundreds TeV energy neutrino astronomy may be at discover edge; underground muon detector, whose vertical string are viewing at best in vertical axis, are polluted (by atmospheric muons) from above, while they are almost blind in vertical up-going directions because of the Earth opacity. At horizons their geometry make them, up to day, quite an un-efficient detector. On the contrary, $\tau$ decay in flight at horizons in an extended air-shower is exploiting the unique noise
free screen (no horizontal air-showers arise beyond the Earth) that allow an optimal signals and easier discover of such amplified UHE $\nu$ astronomy.

2. Why an UHE $\nu$ astronomy at hand?

Since Galileo we enjoyed of an optical view first of the planets, stars, and later galaxy maps while, since last century we enlarged the astronomical electromagnetic windows in radio, infrared, UV, X, $\gamma$ with great success. Now a more compelling UHE $\nu$ astronomy at EeVs energy is waiting at the corner. It is somehow linked to a very expected new particle astronomy: the UHECR at GZK energy $\geq 4 \cdot 10^{19}$eV: it must be a limited and nearby one (tens Mpc) because of cosmic BBR opacity. There have been since now two successfully neutrino astronomy at opposite low energy windows: the solar and the supernova ones. The solar ones has been explained by Davis,Gallex, SK, SNO experiment in last four decades opening the $\nu$ physics to a solar neutrino mass splitting and a clear probe to its mixing behavior. The supernova SN 1987A was an unique event that anyway had a particular expected signatures at tens MeV. On going experiment on cosmic supernova background in S.K. are at the threshold edges, possibly ready to a discover of this cosmic background. However there is a more exciting and energetic $\nu$ astronomy at PeV and EeV energy associate to the evidence of charged UHECR spectra at EeV and tens hundred of EeV band. Indeed any EeV CR originated nearby an AGN or GRB or BL Lac jet will be partially screened by the same source lights leading to a consequent photopion production, associated with PeV secondary neutrinos. In a much simpler and guaranteed way, at energy about $4 \cdot 10^{19}$eV, UHECR should propagate in cosmic photon black body, being partially arrested by photopion productions, (GZK cut-off), leading to EeV neutrinos all along the Universe confines. These UHE $\nu$ components, consequence of the GZK cut-off, are called cosmogenic or GZK neutrinos. Their flux may be estimated by general arguments and there is quite a wide consensus on such neutrino GZK flux at EeV energies. These guaranteed neutrinos may be complementary to possible expected higher energy neutrinos (at ZeV energies) whose role might explain UHECR isotropy and homogeneity being originated at cosmic distances. In this model UHECR born as nucleons via $\nu + \bar{\nu}_R \rightarrow Z \rightarrow X + N$ (Z-burst or Z-shower model) \cite{4,32,31} are overcoming present (AGASA,HIRES,AUGER) un-observed local (VIRGO,PERSEUS) source distribution, as would be prescribed by naive GZK cut-off. However GZK neutrinos and Z-Burst neutrinos at EeV are making comparable flux predictions and we shall restrict to the simplest GZK flux assumption.

2.1. Six Neutrinos in search of an Author and an Astronomy: historical connections

The consequent three flavour matter-anti-matter neutrino states, $3 \times 2 = 6$ neutrino actors in search of an author are linked to a wide historical sequences of
Figure 2: The Six main actors (Pauli, Majorana, Pontecorvo, Conversi, Steinberger, Perl) in Lepton search among the great corner shadows of Dirac and Einstein-Bose (Fermions-Bosons); B. Rossi (cosmic rays) and SK, SNO, K2K achievements at the center remind us of the cosmic rays neutrinos, their mixing and the new tau neutrino role in air-showers.

nomes: Pauli (by energy conservation law), Majorana (because of a possible matter-antimatter overlapping), Pontecorvo (for neutrino oscillations among themselves or among different flavour nature); indeed a main actor that opened the key question for neutrino mixing and multi-flavour leptons is the muon (Who ordered that?): its discover was made by Conversi, (Pacini, Piccioni) on 1948 opening the road to much later and actual lepton and quark family frame (clarified by Gell’mann, Neeman, Cabibbo, Glashow, Salam, Weinberg, since last 40 years). The muon neutrino discover is linked to Leon Lederman, Melvin Schwartz and Jack Steinberger, shown on the right side picture. The fundamental discovers in cosmic ray, disentangling their muon and pion composition, has been inspired by a long list of revolution and instrumentations invented by Bruno Rossi (in the central picture). His main role in CR history was fundamental for understanding the complex air-shower and in opening X-gamma astronomy; his results are the backbone of most paper in this field. The additional actor on neutrino frame is the more recent Perl’s discover in 1970 of a third unexpected lepton, the tau, whose associated neutrino has been experienced only thirty years later on this century. Many more discovers by Davis, Gallex, S.K., SNO, K2K, are testing the earliest B.Pontecorvo predictions and their cosmic roles.

All over those three light neutrino flavours (verified also at LEP on 1990s by the Z boson width) the role of Dirac neutrino is competitive to Majorana one and doubling neutrino states are possible. The recent definitive discover of atmospheric
3. Why upward tau air showers are linked to neutrino mass and mixing?

The tau production is limited, in general, to high energy charmed mesons, whose productions are rare and severely suppressed respect to lower energy pions ones. For this reason \( \nu_\mu, \bar{\nu}_\mu \) astronomy had a major attention in last century, also for the deeper \( \mu^+, \mu^- \) penetration with respect \( e^+, e^- \) and unstable tau. However the definite \( \nu_\mu \leftrightarrow \nu_\tau \) (SK data) disappearance and the flavour neutrino mixing has given to \( \nu_\tau, \bar{\nu}_\tau \) a new life and attention. Indeed the additional possibility to oscillate, even at highest energy \((10^{19} \text{eV}) \) energy and lowest mass splitting \( (\Delta m \simeq 10^{-2} \text{eV}) \), is guaranteed by the huge stellar galactic and cosmic distance \((\gg \text{hundred pc})\).

\[
L_{\nu_\mu \to \nu_\tau} = 8.3 \text{pc} \left( \frac{E_\nu}{10^{19} \text{eV}} \right) \left( \frac{\Delta m^2_{ij}}{10^{-2} \text{eV}^2} \right)^{-1}
\]

(1)

respect to the above oscillatory one. In some sense this \( \tau \) neutrino astronomy offers additional proof of \( \nu \) mixing. It should be noticed that on principle \( \nu_\mu \to \nu_\tau \) appearance may (or is going to) be revealed in SK events. However the conjure of \( \tau \) large threshold energy \((4 \text{GeV}) \) and the small Earth radius size make this possibility a different or marginal one. On the contrary a solar flare neutrino \( \nu_\mu \) may travel and reach the Earth at threshold tens GeV energy and convert itself successfully into \( \tau \) leading to a possible \( \nu_\tau \) neutrino astronomy from solar flare \[15\] 

3.1. Neutrino Showering in Universe: Why a Z-Burst solves GZK puzzle?

As a cosmic ray hitting atmosphere, in analogous way may shower an UHE \( \nu \) hitting a relic \( \bar{\nu} \) in hot and spread dark halo, may lead to Z boson and its decay. Among the UHE secondaries nucleons (and anti nucleons) one may reach the Earth appearing as an UHECR. Because the relic neutrinos \( \nu_\tau \) mass may be about or below 0.4 eV the incoming UHE \( \nu_i \) should be above \( E_{\nu_i} \simeq M_Z^2/m_{\nu_i} \simeq 10^{22} \cdot (m_{\nu_i}/0.4 \text{eV})^{-1} \) eV, while the final nucleon shares an average \( E_p \simeq 2 \cdot 10^{20} \text{eV} \cdot (m_{\nu_i}/0.4 \text{eV})^{-1} \), in agreement with AGASA data. The UHE ZeV neutrinos may escape BBR opacity and connect UHECR to cosmic sources and explain their cosmic homogeneous and isotropic imprint (as most observed UHECR maps show). While recent report from Hires and AUGER seem to disclaim the AGASA spectra absence of a cut, the missing nearby UHECR sources correlated with these UHECR events leaves (in
Figure 3: A schematic cosmic map where ZeVs neutrinos from BL Lac at cosmic edges, interact on relic one leading to Z-Burst and showering into UHECR. The white ellipse (a ten of Mpc. size) contains most of a super-galactic cluster where a relic light (0.4 – 0, 1 eV.) neutrino clouds are smeared as a diffused hot dark matter component. The Z-boson decay contains UHE neutrons (white color secondary arrows) and proton and anti-proton longer life UHECR. An analogous (but more exotic process takes place for UHE neutralino scattering onto relic neutrino leading, via sneutrinos resonances, to UHE showering in space. Because of the higher mass of sneutrinos are generated at higher (than neutrino), tens -hundred ZeV neutralino energies. See [9, 7].

Figure 4: The cross-section for UHE neutrino-anti-neutrino s-channel leading to resonant Z-Boson decay; additional WW and ZZ channels are also shown. The possible mild relativistic relic neutrino distribution will induce a Doppler shift whose smearing role will lead to a "broken-tower" peak shown in figure. The consequent Z-Burst shower will feed electro-magnetic (electron pairs, gamma) and nuclear components; the latter may be source of UHECR escaping GZK cut-off. See [9, 11].

Figure 5: The energy fluence in radiation and particle in our Universe and by solar neutrino influence. The relic neutrino masses induce a possible dominant component at different (almost equal or non-degenerated) eV masses. Their presence will rule a Z-Burst showering and an UHECR tails just at the edge of the cosmic ray scale. Similar showering maybe born by UHE ZeVs neutralino scattering into relic neutrinos via sneutrino resonances. The lighter the neutrino mass the higher its UHECR influence, up to ZeV UHECR edges. See [9, 11].
my opinion) still open the GZK puzzle. The presence of non degenerated lightest neutrino mass ($m_\nu \leq 0.1eV$) may offer the presence of multiple Z-resonant UHE neutrino energies corresponding for example to $E_\nu = 4 \cdot 10^{22}(m_\nu/0.1eV)^{-1}$ eV or $E_\nu = 8 \cdot 10^{22}(m_\nu/0.05eV)^{-1}$ eV. If this will be the case we must foresee for such a lightest case, a future highest energy bumps in UHECR: indeed the possible maximal atmospheric neutrino mass (assuming negligible all other neutrino masses), $m_i = \sqrt{\Delta m^2_{atm}} \simeq 0.05eV$, implies ultimately a limiting resonance at $E_\nu = 8 \cdot 10^{22}(m_\nu/0.05eV)^{-1}$ eV, whose consequence may reflect in an unexpected energy injection and un upper limit UHECR bump at $E_{nucleon} = 1.6(m_\nu/0.05eV)^{-1}$ ZeV energy edge. This bump maybe mitigated by lower neutrino clustering density, but also increased by little larger cosmic (GZK) distances. The AUGER and the EUSO detectors may reach these extreme goals possibly discovering not a neutrino spectra "deeps" but the more concrete imprint of the emergence in the UHECR spectra edges of relic $\nu$ masses shadows. It should be noted that the even extreme light relic $\nu$ masses (0.1eV) may be spread inside cosmic volumes whose radiuses may be comparable with GZK cut-off. This possibility implies an efficient GZK suppression of Z-Burst secondaries gamma component, at $10^{19}$eV, because they are much more absorbed than nuclear UHECR component at this energy. This peculiarity may reconcile the apparent absence of $\gamma$ UHECR at $10^{19}$eV signals, while being still consistent to most Z-burst model predictions. Let us remind that a possible very light relic $\nu$ at nearly relativistic regime should spread the corresponding $\nu\bar{\nu}$ Z resonance peaks leading to a smoother bump whose "broken tower" shape has been first recognized and recently re-discovered by many others authors.

4. Why Air showering by W$^-$ resonance and $\nu_\tau \rightarrow \tau$, $\bar{\nu}_\tau \rightarrow \bar{\tau}$, in air?

As the Z boson peak favors UHE neutrinos in Z-shower model for light neutrino masses ($E_{\bar{\nu}_e} \simeq m_Z^2/2m_\nu \simeq 10$ ZeV $\frac{0.4eV}{m_\nu}$), in the same way $\bar{\nu}_e e \rightarrow W^-$ resonance ($E_{\bar{\nu}_e} \simeq m_W^2/2m_e \simeq 6.3PeV$) favors energetic $E_{\bar{\nu}_e}$ hitting and showering beyond mountain barrier (as well as within air horizontal edges). The advantage of a mountain lay is double: a sharp filter for all the horizontal hadronic air shower (and even muon tails) and a dense beam dump where $\bar{\nu}_e e \rightarrow W^-$ or $\nu_\tau, (\bar{\nu}_\tau) + N \rightarrow \tau(\bar{\tau}) + X$ may take place. These events are double (first $\nu N$ or $\bar{\nu}_e e$ event and later a $\tau$ decay); in water the phenomenon has been noticed nearly ten years ago, see [25]. The idea of this $\tau$ showering in water was been considered as the double bang signatures, rarely observable in km$^3$ detector. The some double bang reformulated in and out, in rock mountains (or Earth) first and out within air, later, was the main proposal discussed first at the end of the previous century. In particular since six years ago, see [13], the upgoing and horizontal air showers has been widely formulated for detention beyond mountain chain, as the Alps and Ande ones. These ideas had been promptly considered for on going AUGER experiment, just nearby Ande mountain chain, see [13][17][26]. Later
on the same idea of old and regenerated horizontal air shower have been considered by other authors \cite{2} as well as by a wide list of additional authors \cite{20, 29, 24, 30}. The difference of the \( \tau \) role in its crossing the Earth lay is in its complex energy loss processes. Ionization, bremsstrahlung, pair production and photo-nuclear losses are suppressing the \( \tau \) primary energy in such way its own lifetime may be shortened suppressing its propagation length. The understanding of the correct interaction length has been noticed by \cite{10} and it has been incorporated on 2000 by \cite{13}, and in the complete final \( \tau \) radiation length \cite{13, 17}. While first and late attempts assumed a fixed \( \beta \) parameter or a linear ones, the \( \beta \) dependence with its logarithmic growth with energy has been considered correctly by \cite{13} (and not other authors) as it has been probed in detail only recently \cite{8}.

5. How penetrating is a \( \tau \) length versus muon one?

One of the most common place in \( \nu \) telescope astronomy is to consider \( \mu \) because more penetrating than \( e \) and \( \tau \) \cite{13}. This is true in the TeV-PeV energy. However the PeV \( \tau \) is already to escape a mountain, decay in flight and amplify its shower loudly, respect to a single \( \mu \) escaping at some energy from a mountain. Moreover the muon logarithmic growth is reached at EeVs by a linear growth of an UHE \( \tau \), mostly because if the lepton is heavier, its electromagnetic loss is smaller. Unfortunately hadronic losses do not allow the \( \tau \) to increase its penetration but \( \tau \) is more penetrating a those UHE regime where \( \nu \) astronomy overcome the atmosphere \( \nu \) noise, see \cite{13}. In more sophisticated approach, not shown here for sake of simplicity, one may estimate the Earth skin to Tau Air-shower for shorter maximal lengths that guarantee a unsuppressed highest Tau escape energy; this minimal Earth skin define a smaller volume and lower tau air-showering rate, but at highest EeVs energy \cite{17}. The behavior of \( \tau \) lengths for most adopted energy losses, the possible definition of a shorter length that guarantee a higher outgoing \( \tau \) energy, all the detailed Earth profile density for escaping \( \tau \) and the consideration of the finite atmosphere size for escaping \( \tau \) air shower, all these details have been analyzed in a tail of recent article \cite{17}. Independent attention has grown in studying the upgoing \( \tau \) flux in km\(^3\) detectors \cite{20, 29, 24, 30}. The general results are not always converging and a summary of the most recently results has been shown (see last fig in ref. \cite{17} for general comparision).

5.1. The table of PDG \( \tau \) air shower

While we have not yet experienced \( \tau \) definitive air showers, we may foresee that any neutrino \( \tau \) astronomy will, soon or later, test the \( \tau \) decay channels. Indeed the main multiple \( \tau \) decay channel are leading to weighted channel and showers described in PDG table. It will be possible, in principle, to verify by ratio of \( \bar{\nu}_e e \to W \to \tau \) monocromatic channel versus \( \nu_\tau + N \to \tau \) channel, the \( \nu_\tau / \nu_e \) abundance and the
Glashow’s neutrino peak. To overcome this neutrino opacity one may consider mountain chains interaction length for both neutrino with nucleons and its peculiar anti-neutrino-electron Glashow telescope. However at ultra-relativistic regime tau reach and overcome the muon tracks, making the heaviest lepton the most penetrating. Because life-time linkage to tau energy and to its energy losses, dominated by hadron and pair production, the tau interaction length is derived by an hybrid transcendent equation comparing energy losses and life-time length.

Figure 6: While tau are extremely unstable and electron are leading to short radiation length, muons are usually the most penetrating lepton; this usually favor underground muon neutrino telescope. However at ultra-relativistic regime tau reach and overcome the muon tracks, making the heaviest lepton the most penetrating. Because life-time linkage to tau energy and to its energy losses, dominated by hadron and pair production, the tau interaction length is derived by an hybrid transcendent equation comparing energy losses and life-time length.

Figure 7: A schematic view of the possible Horizontal Tau Air-showers at EeVs energy versus a lower PeV vertical up-going Tau Air-Shower. In the left side insert the cross-sections for UHE anti-neutrino with electrons, mediated by $W^{-}$ and the almost comparable UHE neutralino scattering on electron leading to $\bar{\nu}_{R}$ whose decay in flight lead also to UHE electromagnetic jet-shower. The consequent interaction length for both neutrino with nucleons and its peculiar anti-neutrino-electron Glashow resonance is shown in the second insert. The Earth diameter in nearly $10^{10}$ cm, water equivalent; therefore the terrestrial neutrino opacity arises above tens PeV energy or inside the narrow resonant Glashow’s neutrino peak. To overcome this neutrino opacity one may consider mountain chains or small (PeV) Uptaus or shorter terrestrial cord, for higher energy Hortaus, that are just at the horizons as shown by the red arrows.
primary flavour mixing. In a few words $\tau$ air shower must be consistent and correlated, in its decay mode by electromagnetic, hadronic and hybrid channel, with well known elementary particle result.

### Figure 8: The possible Tau decay channel and corresponding air-showering mode

| Decay | Secondaries | Probability | Air-shower |
|-------|-------------|-------------|------------|
| $\tau \rightarrow \mu^- \bar{\nu}_\mu$ | $\mu^-$ | $\sim 17.4\%$ | Unobservable |
| $\tau \rightarrow \mu^- \bar{\nu}_\mu$ | $\pi^+$ | $\sim 17.8\%$ | 1 Electromagnetic |
| $\tau \rightarrow \pi^- \nu_\tau$ | $\pi^-$ | $\sim 11.8\%$ | 1 Hadronic |
| $\tau \rightarrow \pi^- \bar{\nu}_\tau$ | $\pi^+$, $\pi^0 \rightarrow 2\gamma$ | $\sim 25.8\%$ | 1 Hadronic, 2 Electromagnetic |
| $\tau \rightarrow \pi^- \bar{\nu}_\tau$ | $\pi^+$, $2\pi^0 \rightarrow 4\gamma$ | $\sim 10.7\%$ | 1 Hadronic, 4 Electromagnetic |
| $\tau \rightarrow \pi^- \bar{\nu}_\tau$ | $\pi^+$, $3\pi^0 \rightarrow 6\gamma$ | $\sim 1.23\%$ | 1 Hadronic, 6 Electromagnetic |
| $\tau \rightarrow \pi^- \bar{\nu}_\tau$ | $2\pi^- \rightarrow 2\gamma$ | $\sim 10\%$ | 3 Hadronic |
| $\tau \rightarrow \pi^- \pi^- \pi^0 \nu_\tau$ | $2\pi^-, \pi^0 \rightarrow 2\gamma$ | $\sim 5.18\%$ | 3 Hadronic, 2 Electromagnetic |

### 6. Eleven Present, Past and Future Experiment in search of a Tau

There are very advanced experiment that ( wherever they are aware or not) might point for Tau Air-Showers, even they were originally thought for other scientific targets. The list of these High energy Showering experiment adaptable to tau Neutrino and Horizontal Showering is here briefly reviewed: 1)Argo, in Tibet; 2) Milagro (and Milagrito) in USA mountains,3) AUGER experiment in Argentina, 4) Space Station Crown Arrays (to be effectively proposed), 5) EUSO telescope, 6) BATSE satellite in CGRO (1991 – 2000 past), 7) ASHRA experiment in Hawaii, 8) CRTNT Fluorescence array in Utah or China, 9) Muon Array Telescope in Jungfraujoch, 10) Cherenkov Telescopes on High Mountains facing the mountains, like Shalon in Kazakhstan. In this view the Magic Stereo (as well as Veritas array) Telescopes facing the Earth edges are somehow ideal. The first Horizons tests maybe done possibly in cloudy and otherwise astronomical useless nights. Here below the images and the captions explaining how those experiments may find Tau Air-Showering by a minimal optimized trigger set up.

#### 6.1. Argo

This large area array inside a deep valley in Tibet may record PeVs Tau air-showers emerging from the mountains around. The nearby Chines-Japanese twin experiment may enlarge the area. The presence of more (tens-hundred) spread (small, few $m^2$ area) elements at hundred meters one from the other, in vertical structure as well as the covering of the inner wall periphery of the detector house, may greatly increase the ARGO ability to reveal PeVs air-showering below the mountain shapes.
The variable opacity to atmospheric GeVs-TeVs muons within the mountain shadows, is a needed test.

6.2. Milagro

The existence of huge pools at peak mountains as Milagro and smaller Milagrito, offer an exiting laboratory to verify (besides TeV gamma backgrounds): the muon horizontal fluxes at horizons; the muon bundle density, flux and structures (in comparison with sea-level Nemo-Decor data, see [6, 27]); finally there is the possibility to discover Up-going muon bundles, whose existence maybe indebted only to Earth Skimming (Uptaus) Air-showering.

6.3. AUGER

As in figures and in captions the Auger experiment offer a unique occasion to Horizontal Tau possibly from the West side toward the AUGER detector; to optimize the ability to disentangle these events one should first observe the Ande shadows (at $87 - 90^\circ$), zenith angles by a simple asymmetry East-West UHECR showering, see [10, 13, 17, 26]. Within the first year of full operation the shadow must be seen. Later on, within the same solid angle of $\approx 2 \cdot 100 = 6 \cdot 10^{-2} sr.$ two event a year by tau Air-showers (via GZK neutrino flux) might be very probably observed see 17. The AUGER Fluorescence detector may enlarge their view also toward the Ande, offering an ideal screen capturing Ande-Tau Showers in horizontal tracks at best. The possibility to use inclined air-shower Cherenkov lights hitting the Fluorescence detector maybe exploited. Multi-telescope coincident Cherenkov detection (while being nearly on axis) of horizontal air-showers maybe applied in all the 12 common directions ($4 \cdot 3$) in AUGER (and 2 for stereoscopic HIRES).

6.4. Space Station Crown Arrays

From the Space there is the most appealing location to search for Horizontal High Altitudes Showers and Horizontal or Vertical Tau-Air-showers (Hortau-Uptau). This project is still preliminary. The crown-array maybe both detecting (tens, hundred keV) gamma secondaries (as well as rarer hundred GeV lepton pairs) as well as Cherenkov lights due to far Hadron and Gamma primary High Energy Cosmic Rays showering from Earth. The array maybe at PeVs-EeVs energy equivalent to few-hundred km. mass neutrino detectors, depending on the telescope sizes and gamma
Figure 9: The possible use of Italian-Chinese ARGO (and its twin nearby Chinese-Japanese array) to monitor, inside a wide deep valley, inclined or horizontal tau air-showers originated by surrounding mountains; the signal may be better revealed by additional array detectors on the walls along the lateral boundaries; these lateral-wall array are in analogy to present Nevod-Decor detector parallelepiped structures, in Russia.

Figure 10: The possible UHECR horizontal or up-going Tau air-showering on Milagro (as well in correlated mode, to nearby Milagrito) while being a TeV gamma detectors: GRB or an active BL Lac at horizons, making nearly 1 – 3% of GRB, SGRs, BL Lac events, might play a role in shining and tracing muon bundles in the Milagro pool waters. As a first estimate, assuming an effective area of few \(10^3 \cdot m^2\) we foresee one or a few events of Upward muon bundles associated to Tau Air-Showers each year, depending on the trigger, the threshold and geometry.
Figure 11: The long Ande chain mountain is offering a unique wide screening shadows (for UHECR) (opening angle $2 - 3^\circ$) and an ideal beam dump (for PeVs-EeVs tau neutrinos) to AUGER array detector. Inside this shadows, that may be soon manifest, rare (a few a year), but quite guaranteed horizontal tau (by GZK neutrino fluxes) air-shower that might be open Neutrino Astronomy windows.

Figure 12: Inclined Horizontal Air-Showers able to trigger both Auger tanks and Fluorescence telescopes, while being in the same axis. This technique, as long the author knows, has never been used to better disentangle horizontal Air-Showers. It may be an ideal detector to observe Tau Air-Showers from the Ande. Their events will populate the forbidden area of large zenith angle at horizons. For this reason it will be useful to: a) enlarge the angle of view of Coihueco (as well as Loma Amarilla and Leones station) toward the Ande; b) to eliminate any optical filter for Cherenkov lights in those directions; c) to open a trigger between the Array-Telescope, or Telescope-Telescope in Cherenkov blazing mode; d) to try all 4 telescope Fluorescence connection in Cherenkov common trigger-mode along all the $6 \cdot 2 = 12$ common arrival directions. Similar connection along the $360^\circ$ view of stereoscopic HIRES telescopes, might be already done testing along their common horizontal 2 axis air-showers (from PeVs up to EeV energy) with high rate (tens-hundreds events a night) and great angular accuracy. In the picture some possible inclined UHECR events shining both array detectors and (by Cherenkov lights) Fluorescence Station; possible twin separated ovals arise by geomagnetic bending.
6.5. EUSO

The project of a telescope facing down-ward the Earth and catching the UHECR has been delayed to the end of the century. However the idea may offer a way to discover beamed horizontal HorTaus at tens EeV energy showering at high altitudes. Few events, 4 – 6, might be observed each year. The EUSO mass equivalent due to Earth-Skimming neutrinos is nearly $100 \text{ sr} \text{ km}^{-2}$ water equivalent, even taking into account the 10% duty cycle of the EUSO activity.

6.6. BATSE

Old generation of Gamma satellite in orbit last decade made (with deep discovers by Beppo Sax) most of our view in gamma astronomy. Present and next generation (Swift, Glast) will enlarge the EGRET astronomy by deeper views. The same skimming C.R. or Albedo and Air-Shower tracing by UHECR (PeVs-EeVs) will naturally arise.

6.7. ASHRA

Three Fluorescence detectors, in a similar way as AUGER telescopes, are monitoring from the top mountains of the Hawaii island the inner area; their detection maybe greatly enhanced by tracing and calibrating higher altitude HIAS and facing the Earth edges, searching the HorTaus at ocean Horizons.

6.8. Jungfraujoch

The existence in the top Europe turistic station of scientific facilities and fast transport made possible a first test of Muon Telescope Array prototype at horizons site. The proposal of a larger area and more numerous detector is in progress and it may compete with Cherenkov telescope also because of light noise independence of the scintillator array.

6.9. CRNT

The proposal of a Fluorescence array within the cliff shadows is going to be considered in Utah and-or in China. The PeV detection will be possible by low noise
Figure 13: Space Station constructed and armed with a Telescope Cherenkov Array and a Gamma Array spread array able to disentangle gamma flashes and arrival lights, from the Earth edges. The possible Tau neutrino nature is imprinted by the arrival direction below the Earth horizons, while the UHECR showers arise at the high Atmosphere (Albedo) edges above. The duration of the signal (micro-second to millisecond), as for Terrestrial Gamma Flashes, is the signature of these Up-going Air-Shower, steady ones are the signature of Gamma TeVs-PeVs air-showering sources. The threshold depends on the Telescope and Gamma detector areas; even the distances from Space Station are nearly 100 – 200 larger than vertical TeV-PeV air-showers on Earth, the beaming is 14 – 20 smaller, with negligible absorption, making a 2 meter square Cherenkov telescope able in principle to observe TeVs gamma sources.

See [16]

Figure 14: Gamma and UHECR Air-Showering (High Altitude Air Showers, HIAS), in Space versus Tau Horizontal and Vertical (HorTau-UpTau) air-showers: while the Atmosphere Earth Skimming at TeVs-PeV gamma photons are showering in high altitude atmosphere (35 – 40 km.), at extreme low air density (about or below 1% os sea level), their Cherenkov beam is about 0.1° at 36 km altitudes. Their air-showering may blaze from 2000 km far away leading to brief, persistent (about two in gamma-X rays or tens second in optical duration), transient gamma and Cherenkov point-like flares, detectable by the present and future Gamma Satellites array. Their exact arrival angle maybe monitored within narrow angles by a Crown Cherenkov Telescopes on the Space Station toward the terrestrial edges. Similar less rare gamma – air – skimming from Tens GeV to hundred GeVs events, might indeed be already hidden in some old records of BATSE catalog, labelled as electrons or particle events. Indeed their puzzling signature of the satellite rise and dawn orbit, as in figure, are notable. The well known discover of brief up-going Terrestrial Gamma Flash by BATSE (1991 – 2000) maybe, on the contrary be indeed indebt to Earth-Skimming EeV neutrino showering (Hortaus) or PeVs Up vertical showers (Up-taus), or to UHECR air-skimming the Earth atmosphere.

See [16]
Figure 15: The apparent correlations between Earth crust contrast, gravity anomaly and the observed location of Terrestrial Gamma Flashes observed by BATSE in last decade (and by RHESSI last two years). The overlap of the TGF events with maximal terrestrial mass density contrast (Mountain chains, sea-islands) in the equatorial belt where BATSE-Compton trajectory laid, favors a common origin of TGF and tau-airshowers. See [13], [17].

Figure 16: The up-going horizontal air-showers whose longest (hundreds of km.) air-showers might be detectable by future Enso project; the project would reveal thousands oh UHECR mostly downward events, as well as hundred of horizontal C.R. airs-showers, whose beam angle is extremely small, because low air density. Within these down-going UHECR air-showers there are 4-6 event a year originated within a wider field of view. One of his greatest proponent and great scientist, that with Prof. Linsley discovered UHECR at GZK edges, Prof. M.Livio, sadly has very recently missed. See [17]
Figure 17: The present ASHRA experiment in Hawaii leading the rush of Horizontal Tau Air-Shower by Fluorescence Telescope Array on the top mountains.

Figure 18: The project experiment in UTAH nearby (ten km.) a cliff searching for Cosmic Ray Tau Neutrino, CRTNT, by Fluorescence Telescope Array.

Figure 19: A novel project experiment in Swiss top-mountain for Horizontal Cosmic Ray Tau Neutrino as well as horizontal muon fluxes.

See [23], [22].
light location and Cherenkov aided discovering techniques.

6.10. Shalon

A Russian proposal leaded by Cherenkov TeV-Telescope is already looking from the mountains terrestrial targets in search of eventual Tau air-showers, finding already a statistics on Albedo air-Showers and relevant first calibrations.

6.11. Eolic Array

On the top of the mountains small crown arrays of detectors may be mounted on the eolian energy stands. The usual sites (mountain) the power supply, the two different hight on the same element may offer a useful place to build an horizontal Air-shower detector, in wild areas and spread surfaces

7. The Veritas and Magic views of Tau Air-Showers at horizons

Cherenkov gamma Telescopes as last Veritas and MAGIC ones at the top of a mountains are searching for tens GeV $\gamma$ astronomy. The same telescope at zero cost in cloudy nights, may turn (for an bending angle $\simeq 10^\circ$) toward terrestrial horizontal edges, testing both common PeVs cosmic ray air showers, muon secondary noises and bundles as well as upgoing tau air-showers. Indeed the possible detection of a far air shower is enriched by:

1. early Cerenkov flash even dimmed by atmosphere screen

2. single and multiple muon bundle shining Cerenkov rings or arcs inside the disk in time correlation

3. muon decaying into electromagnetic in flight making mini shower mostly outside the disk leading, to lateral correlated gamma tails.

We estimated the rate for such PeVs-EeV events each night, finding hundreds event of noises muons and tens of bundle correlated signals each night\textsuperscript{19}. Among them up-going Tau Air-Showers may occur very rarely, but their discover is at hand for dedicated $360^\circ$ crown Arrays\textsuperscript{16} (and arrays of these crowns) in correlation among themselves and scintillator detectors.

The timing of these signals,their expected event rate at PeVs in a night time of Magic at horizon ($87^\circ$ zenith angle ) and their easy signature has been reported recently by Fargion\textsuperscript{19}. More over the very simple exercise of the estimate of the air cone volume observed at the horizons by MAGIC shows a value larger than $10^3Km^3$ corresponding to a mass volume larger than $1km^3$ water equivalent. This volume at
Figure 20: The possible horizontal air-showering by a GRB or an active BL Lac, whose UHE anti-electron neutrino might resonance with air electrons at Glashow PeVs energies (or in Tau air-showers at higher energy), making nearly 3% of these GRB, SGRs, BL Lac sources laying at horizons for Magic Telescopes. The mass observed, as estimated in figure, within the air-cone exceed the $km^3$ water mass, even if within a narrow solid angle ($\simeq 4 \cdot 10^{-3} \text{ sr.}$)

Figure 21: As above EeVs tau are originated in the Earth crust and while escaping the soil are testing $\sim 70 - 100 km^3$ volumes; later UHE tau may decay in flight and may air-shower loudly toward Magic telescope, within an area of few or tens $km^2$.

Figure 22: The possible inclined UHECR air-showering on Magic facing the sea side. Their detection rate is large (at zenith angle $80 - 85^\circ$) (tens or more a night) nearly comparable with those at zenith angle $87^\circ$ already estimated; these mirror UHECR shower, widely spread in oval images on the sea (depending on the sea wave surfaces), their presence is an useful test for Magic discovering of point source PeV-EeV UHECR air-showers at horizons. While previous configuration above horizons may correlate direct muon bundle and Cherenkov flashes, these mirror events are polarized lights mostly muon-free, diffused in large areas and dispersed in longer time scales, mostly in twin (real-mirror-tail) spots. On the contrary Up-going Tau air-showers from the sea are very beamed and thin and un-polarized and brief.
Figure 23: The horizontal air-showers by far hadron differ to an up-tau air-showers, whose younger electromagnetic and muonic density is greater and much larger; in the figure the two different signature of the flux densities assuming a Magic telescope observer (not in scale), and an ideal downward far nucleon and a nearby Tau EeV air-showers event.

Figure 24: Ideal arrays of crown scintillators on wind eolic stations.

Figure 25: Ideal arrays of Cherenkov Crowns Telescopes in Canaries and an equivalent twin Crown Array Balloon in flight; similar arrays maybe located in planes or satellites.
Glashow resonance energies make MAGIC the must wide $\nu$ detector. The some estimate even at smaller solid angle, below the horizon leads a large mass for EeV neutrinos, encompassing volumes and masses as large as $10^2 km^3$. These detectors are active only within a narrow view, but during peculiar rise and down of BL Lac, AGN or Crab like sources, or in coincidence with GRBs along the horizon, the masses enlisted are huge and relevant. To make the detection permanent and in wider angle view the ideal crown array of MAGIC-like telescope on circle and their twin or multiple array structure at few km distance, will guarantee a huge capability to observe an event or few event of $\tau$ upgoing shower during a month, within a few tens of UHECR above the edges.

8. Conclusions

Because muon tracks are mostly of downward atmospheric nature the underground neutrino telescope are tracing rarer upward ones mostly of atmospheric origin; higher energy upgoing astrophysical neutrino signals are partially suppressed by Earth opacity, and are unique tracks. On the contrary $\tau$ air shower at horizons is spreading its signal in a wider area leading to populated (millions-billions) muon and gamma (as well as electron pairs) bundles in their showering secondary mode. This amplified signal may be observed and disentangled from farer and filtered UHECR, in different ways and places: mountains, balloons, satellites with different detector array area and thresholds. The advantage to be in high quota is to be extending the visible target terrestrial area and solid angle, as well as to let a longer tau flight distance (and energy), and to enlarge the air shower area; to make an intuitive estimate the Tau air-shower size area, at tens PeVs-EeVs, (detectable at horizons within a lateral distance as large as 3 km. from the main shower axis by a telescope like Magic), is nearly $30 km^2$; at EeV energy the equivalent detection depth crossed by the tau lepton before the exit from the Earth reaches $10 - 20 km$ distances; the corresponding detection Neutrino volume (inside the narrow, conic $10^{-3} sr.$, shower beam) is within $30 - 60 km^3$, in any given direction, see [10]. A few events of GRBs a year may be located within these horizons, as well as AGN and BL Lac in their flare activity. In such occasions Magic, Veritas and Hess array are the most sensitive neutrino telescope at PeVs-EeV energy. Even on average, for a present $2 \cdot 2^\circ$ view of Magic, at present energy thresholds, such telescopes (for Neutrino at Glashow PeVs energy windows), are testing a total mass-solid angle a comparable or larger than to $10^{-2} km^3 sr.$, an order of magnitude comparable with the present AMANDA detector. The very possible existence of blazing Cherenkov noises in present Auger, Hires, Magic views should become a very radical signal in such a Copernican Tau attitude. The role of an Array in mountains, balloons, planes and satellites for horizontal air-showers will rejuvenerate CR and it will open high energy Neutrino eyes to the Universe. In conclusion a maximal alert for the Neutrino air-showering within the Earth shadows is needed: in
AUGER, Milagro, Argo, as well as in ASHRA, CRTNT, Shalon Telescopes the signal is beyond the corner. In particular the Magic (and Veritas) arrays telescopes facing from the mountains the Horizons edges may soon test our proposal leading to such crown arrays. In a sentence we believe that the UHE Neutrino Astronomy is beyond the corner, Tau is its courier and its sky lay just beneath our own sky: the Earth.

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