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Paucity of downward UHE neutrino tracks in Icecube versus unexpected huge KM3-230213A event : solving the puzzles?

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Recently the ARCA array detector published the down-ward-horizontal event: the KM3-230213A. It appeared as the most energetic neutrino ever observed: about 200 PeV ($2 \cdot 10^{17}$ eV) up to EeV (10^{18} eV) energy. This huge value, is puzzling. It is not statistically consistent with several upper bound derived by two greater and longer life detectors: by ICECUBE and in particular by AUGER array. Asymmetry in recent ICECUBE neutrino alert tracks upward and downward at same horizontal angles as ARCA one, suggest that they are mostly polluted atmospheric muon bundles. This paucity also disfavor the skimming neutrino interpretation by ARCA. We suggest that the array floating and bending in the deep sea may lead, sometime, to a misleading geometry that is pointing to a wrong arrival angle direction: a much less horizontal muon (neutrino) track respect to a much real one, more inclined and vertical, due to atmospheric muon bundle or charmed single event. Contrary to present argument, if such a rare event would be soon rediscovered in data or re-observed, it would open the road to a new guaranteed Tau neutrino Astronomy. At EeV energy such upward tau air-showers should shine AUGER telescopes or blaze future satellite in Space. A previous model in astrophysics considered energetic $E_\nu >> 100$ EeV, neutrino scattering, onto cosmic, relic, light mass ones. Their ultra-relativistic Z boson resonance formation and its decay in flight would produce hadron UHECR relics around tens-hundred EeV energy. Explaining how sources located at far distances, above the usual GZK hundred Mpc, cut off ones, may shine and cluster in AUGER or TA data.

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1. Introduction

The KM3-230213A highest energy muon neutrino event due to its horizontal muon is puzzling. The ICECUBE cubic kilometer is a much wider and much older array than the more recent ARCA array. It had never observed such kind of energetic tracks. Because of neutrino oscillation, a correlated upward Tau air-shower would be observed within three thousands kilometer area in AUGER, Argentina. Indeed, such muon neutrino track in KM3-230213A should have a guaranteed companion, at hundreds of PeV, 10^{17} eV or even EeV 10^{18} energy, a tau neutrino. A necessary mixed flavor component along wide neutrino cosmic flights. Such an up-going horizontal tau neutrino had to interact sometime on the AUGER rock surface, producing, by their up-going tau at horizons. The heaviest known lepton [1]. Its first interaction and its soon decay at D_τ distances ($D_\tau = 50m \cdot [E_\tau/10^{15}eV]$), should be observable at PeV energy in ICECUBE [2] or first, hidden in the soil and later in the air, [3], shining luminescent signals in telescopes. At best, in AUGER, at EeV energies. But they were never discovered by AUGER or by a comparable Telescope Array, TA. Based on the recent ARCA record, two years ago, and previous studies [4], one would expect nearly 30 – 90 of such events in AUGER, depending on their spectra, within nearly 20 years of records in AUGER. Such an absence as well as the negligible presence of PeVs downward ICECUBE alert tracks at similar down-horizons , suggest a solution: an un-noticed, inclination of the Km3 array net under the variable deep sea currents.

1.1 A brief history of the lightest revolutionary particle, the neutrino

Nearly 95 years ago, end 1930, W.Pauli, contrary to N.Bohr and others, wrote an amazing letter to Lise Meitner [5], while being absent in a fundamental physics meeting in Tubingen . It started with the famous words: "Dear Radioactive Ladies and Gentelman... ". Marie Curie and Albert Einstein were among the audience. Pauli proposed the un-expected existence of an "in-observable" neutral particle : a lightest evanescent "neutron" , soon later re-named by E.Fermi, as a "neutrino". This idea was a necessary attempt to overcome the apparent violation of the beta-decay energy [6]. Pauli was right on such particle existence, but just 26 years later, on 1956, the neutrino, in disagreement with Pauli prophecy, was revealed. Just a couple of years before his death. Later, the discovery of a new lepton, the muon, and its associated neutrinos forced B.Pontecorvo [7], (and others [8]), to consider a neutral mixed flavor particle state. Their necessary tiny masses could link different lepton components: the electron, the muon and finally, since 1975, thanks to M.Perl discovering, the heaviest tau. The precise neutrino mass measure suffered a long sequence of inexact proposals over the last decades. Let us recall a few: on early 1980 an apparent experimental value of ten eV neutrino mass was widely accepted in astrophysics and cosmology. Its role was solving the dark matter puzzle of the galactic halo and the dark mass closure of the universe. Its role was also in agreement with the first unified particle models [9]. It has been soon proposed the possibility of such a light neutrino to reach us with a detectable time lapse from an associated massless gravitational wave burst from Super-Novae, SN explosions. Rare stellar collapse event occurring both in galactic or near LMC or Andromeda galaxies. Explosions also occur in the tidal disturbance of the NS-NS collapse event [10], or in a rare GW-GRB event [11]. The neutrino particle with a mass bending at the relativistic regime does not differ much from the massless case [12]. However, the light mass of the left-handed neutrino implied, by Lorentz transform, the existence of a right-handed state, with a much weaker interactions. The role of tiny Dirac-Majorana neutrino masses in the early synthesis of nuclei [13] was noted. The early thermal right-handed neutrino interactions [14], and its later multi-fluid galaxy gravitational clustering [15], had been revealed. Such a multi-clustering by dark matter components at different temperatures and masses [16] (as a right-handed neutrino, SUSY neutralino, or other weak particles [17]), their different gravitational clustering times and masses, might be, incidentally, related to the very recent (unexplained) earliest galaxy populations [18], and the early massive Black Hole presence [19]. [20]. Since 1980 several authors have published unexpected claims on the neutrino mass: for instance, on 1985 J.J Simpson claimed the presence of a heavy, 17 keV neutrino mass component [21]. This possibility was in severe tension with the astrophysical and cosmological data. Soon it was dismissed. Later on, following the dozen of SN 1987 neutrino cluster events, most models were favoring much lighter neutrino masses. The Kamiokande atmospheric neutrino mixing tested on 1998 and the SNO experiment on solar neutrino flavor oscillations and mixing both decreased the hopes for such a dominant neutrino cosmic role. They suggested a very light $<$ 1 eV neutrino mass. But it opened the road to the τ neutrino Astronomy [3]. The eventual role of such a cosmic relic eV neutrino mass, in a hot dark halo, as an effective beam dump for ZeV (10^{21} eV) cosmic UHE neutrinos had been advocated [22] to solve the new not explained UHECR , Ultra High Energy Cosmic Ray, $E > EeV$, event noted on 1995. Apparently they correlated with very far AGN hadron sources, at distances above the so called GZK cut off [23][24]. Most recent signatures of UHECR lightest nuclei composition, their additional "Hot Spot" clustering, point today mainly to local AGN. They represent and fit better a nearby local origin of UHECR [25]. A more recent and precise cosmology models needed lightest $<$ 1 eV, neutrino masses. Above this value , around half of the Z boson mass, the eventual fourth neutrino role has been considered by several authors in the past decades, all within astrophysical and cosmic constraints. A fourth lepton family model is still waiting for experimental confirmations [26],[27]. In conclusion late discovery [1] of the heavier, τ , completed the standard elementary particle frame: six lepton (three charged, three neutral) and six quark. The three neutrino production in terrestrial atmosphere are mainly made by muon and electron ones; however, their flavor mixing at large galactic and cosmic distance flight guaranties the comparable presence for the rarest tau neutrino, as abundant as other ones. Such an astrophysical ν_τ and its eventual consequent tau, which being so much unstable, behave, at GeV-TeV as a unique cascade event. However, at energy above hundred TeV or PeV and above , the $\nu\tau$ interaction in ice and its tau decay are well separated, offering, in principle, a characteristic double bang in underground signature in ICECUBE [2] [28],[29]. In addition, any energetic tau ($E_{\nu_\tau} >> PeV$) escaping from a mountain or rising from Earth's soil can decay in the air, producing an upward-flowing tau air-shower [3], (often incorrectly referred to as the skimming neutrinos [30]) . Such hundreds of PeV $10^{17} eV - 10^{18} eV$ energetic tau neutrinos could be well be observable in AUGER or in Telescope Array detectors [4]. As rare up-going air-shower. As we shall see in the present article, their absence at EeV energies implies a serious bound to the ARCA discovery.

1.2 CERN-OPERA 2011 events: the faster than light neutrino?

A more surprising historical claim on the neutrino nature occurred in September 2011: OPERA and CERN experiments declared that they observed a neutrino signal flight that was faster than light. An imaginary neutrino mass acting as a tachion. Two days [31] and two weeks [32] later, the claim had been confuted by theoretical arguments. The Supernovae 1987A neutrino burst timing and the solar neutrino mixing, among electron and muon flavors, did not allow such a result. Only six months later, more accurate tests from ICARUS [33] confirmed the respect of special relativity. The OPERA group, found that a tiny time delay led to the wrong experimental interpretation. Therefore, the special relativity still applies to neutrinos, as it should. Any small geometrical error may disturb and fake even most great experiments.

1.3 The ARCA 2023 KM3-230213A : the highest energetic neutrino ?

The past decades of ICECUBE and of AUGER array records are statistically in tension with the unexpected huge 2023 neutrino event KM3-230213A in ARCA [34]. The contradictions are numerous [35]. Tau air-showers by EeV neutrinos in AUGER should be well observable: last two decades records in AUGER assuming the nominal KM3-230213A event rate, would produce about 70 events [4]. No one had been discovered yet. The huge ICECUBE mass detector and its life time exposure overcome the ARCA one at least by an order of magnitude. This sounds statistically un-probable. An EeV neutrino has an ideal origin: to be a relic [36] of the opacity [24] , [23], due to the decay of the UHE Delta barion resonance into pions. This candidature is not much consistent with such KM3-230213A event. Indeed , assuming a common cosmic UHECR spectra, the most recent of the AUGER, composition data, [37] had shown that the proton presence above a few $10^{18} eV$, energy is negligible. Consequently, the Delta resonance in GZK cutoff is no longer tuned with a proton energy at $6 \cdot 10^{19} eV$ energy and with the present cosmic $T_o = 2.7K^o$ thermal bath. One should require a hotter cosmic background to be hit by a few $10^{18} eV$ proton. This may take place only at a minimal temperature , at least as $T_{z=10} > 27K^o$, much hotter than the present. This may require early cosmological stages, at a redshift $z > 10$. However, the same later cosmic expansion would once again reduce the final energy of the GZK neutrino secondary, reaching us, in our days, with an energy $E\nu < 10^{16} eV$ and not at the (observed) and expected $E\nu > 10^{17} eV$ ones. There are nevertheless independent processes capable of accelerating the AGN jet and, within the same photons and proton beam flow, producing UHECR Delta resonances. This processes has been recently suggested , at smaller space and energy scale, for the micro-quasar precessing jet, such as the galactic SS433 one [38].

2. The paucity of downward versus upward ICECUBE neutrino alert events

Among nearly 274 events in 2023 ICECUBE alert tracks at maximal energy, most alerts are upward ones, see Fig 1. This asymmetry must be related to a severe veto for such downward muon tracks, mostly of atmospheric nature. Such a veto has to reduce the over-abundant downward cosmic ray noise. This filter is also obtained by the on surface ICETOP array. This surface array is not present in the km^3 sea array. At horizons (+/-9°) where the downward and upward beam dump masses are very comparable, see Fig.2, the asymmetry is within 111 events , only 34 point down , while 77 are upward: the probability P to occur by chance is quite rare: only $P = 1.5 \cdot 10^{-5}$.

This suggests that such horizontal, down-ward inclined tracks in ICECUBE are mostly undesired atmospheric muon tracks. This must also be true for the Mediterranean sea km^3 array. The more extensive sky asymmetry for all alarm events , 274, is mainly 213 , pointing upward events

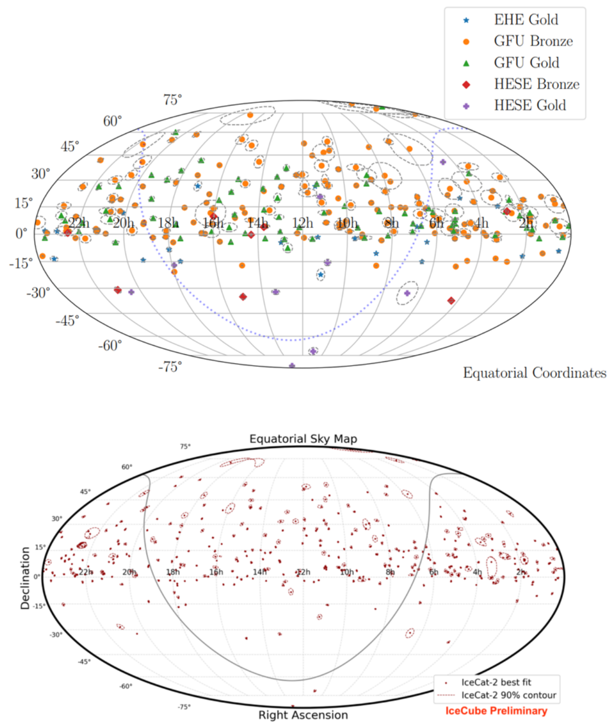

Figure 1: The ICECUBE alert tracks recorded in last years in celestial coordinate- The up-side of each figure point to the North of the Sky. Consequently most event in South Pole array are coming from the North (up-going) , while much less are reaching from the South (down-going tracks). The figure above, based on ICE-Cat1 catalog, refer to the late 2024 data [39]. The figure below is based on the up dated recent but preliminary ICE-Cat2 catalog of events, shown in 2025 [40] The two figures differ by a minor angular definition and by 25 additional events in the 2025 ICECat2 ; [40]

while only 61 are downward ones. For such a rate in a binomial case, the probability of happening by chance is as low as $P = 3.3 \cdot 10^{-9}$.See Fig. 2

Recall that a muon neutrino at an energy above 30 TeV energy should suffer absorption while crossing the whole Earth. Therefore, this asymmetry in the entire sky , see Fig.3 is more meaningful than that shown in Fig.1. For the whole up/down sky alert ICECUBE event, until 2024, observed by ICECUBE, 274 tracks, most of them 213 , are pointing up-ward. Only 61 down-ward. The binomial probability P that occurs by chance is about $P = 3.3 \cdot 10^{-9}$. The Earth opacity for such hundred TeV neutrino up-going tracks implies an additional upward neutrino asymmetry. All of these critical considerations suggest an eventual misleading interpretation of the data. But they do not offer any solution to the puzzle.

2.1 A key difference: a frozen static ice array versus a floating in sea one ?

The main difference between ICECUBE and the ARCA sea array is the medium in which the optical elements are positioned. ICECUBE holds the array elements within a frozen, static, ice in the South Pole. The ARCA km^3 array is located in deep sea, where the detector elements are anchored in 3 km depth in the soil. The array is floating , while connected in columns, bounded

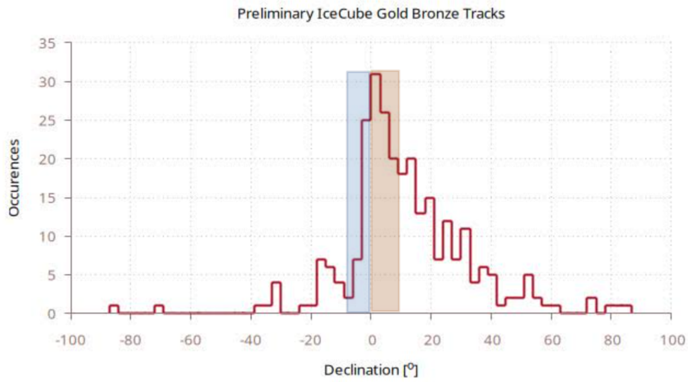

Figure 2: The asymmetry among the $+/-9^o$ event tracks. The paucity of downward tracks imply that the atmospheric noise is greatly polluting most of these horizontal-downward events, at similar arrival angle as the ARCA Km3 event, KM3-230213A.

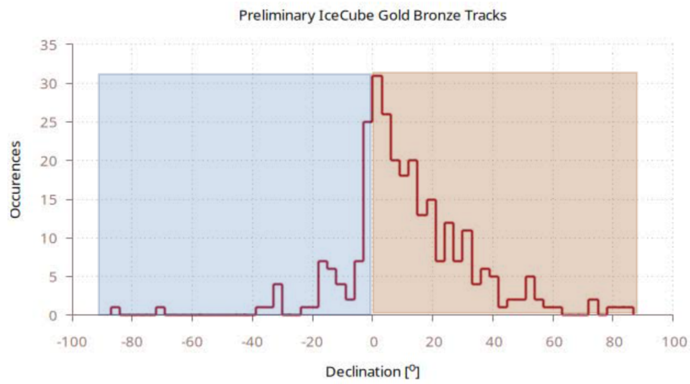

Figure 3: The asymmetry among the up and down ward event tracks. The paucity of downward tracks,(binimial probability P to occur by chance is about $P = 3.3 \cdot 10^{-9}$, imply that the atmospheric noise and its filtering is excluding most down-ward tracks as polluted ones.

deep in the water. The sea water is not static as ICECUBE ice. Therefore, variable inclination is the difference. Nevertheless, the KM3-230213A event was, in general, real, bright, and sharp. The normalized number of photons in KM3-230213A was $N_{PMT} = 3,672$. Any deep sea current may blow into the array, it may bend, and curve their element position. changing the array profile. Imagine, for example, the Pisa tower inclination. A few degree bending can offer a distort view of the array coordinate system. The KM3-230213A. was apparently only 0.8° degree down-ward: just where ICECUBE excluded most of its events, by its filter veto for atmospheric noise ; see Fig. 2, 3. Among nearly 274 events in 2023 ICECUBE alert tracks at maximal energy, most of them are upward. There must be a severe veto, due to atmospheric muons, for such downward tracks. This veto was also possible thanks to the IceTop array filter. At horizons (+/-9°) where the downward and upward beam dump masses are comparable, the asymmetry is , within 111 events 34 down , 77 upward: the probability of such an occurrence, by chance, is quite rare: $1.5 \cdot 10^{-5}$. Therefore, the rise of an UHE neutrino in such a horizontal downward sky is quite puzzling.

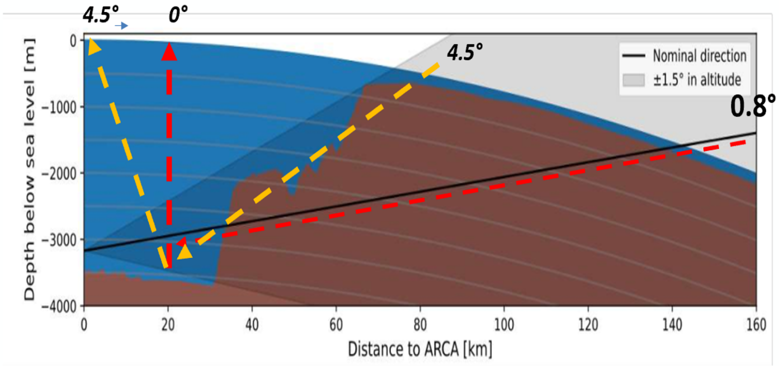

Figure 4: An exaggerated geometry showing a downward-inclined charmed muon track (yellow large dashed line) . The alternative neutrino track (red smaller dashed line) following ARCA event interpretation [34]. The horizontal version (standing for a neutrino) versus a more inclined, vertical geometry. This inclined geometry could offer an atmospheric muon interpretation

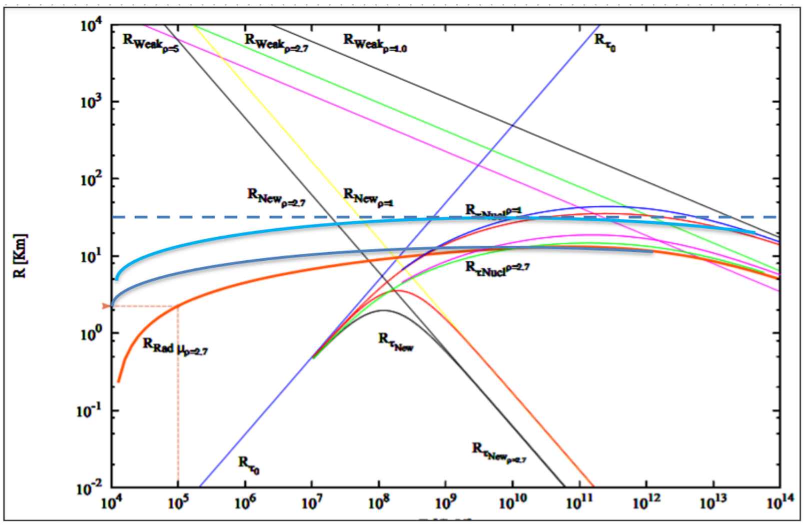

Figure 5: The different expected survival distances for muon and tau assuming their corresponding energies. The orange range curve has been here updated by a light blue curve, based on earlier articles:[3],[4]. At $\theta >= 7^o$, or at least $\theta > 5^o$ inclination, an energetic , EeV, atmospheric charmed muon might reach, the deep sea, respectively, nearly 20 up to 28 km distances, within the muon survival track distance. Easier possibility to reach at high energy for a more bent array $\theta >> 7^o$

3. A pragmatic Conclusion : the critical view

The most probable solution of the ARCA puzzle is that the rare bending (in deep sea by sudden current) of the ARCA vertical array into a more inclined one led to a misunderstanding. A downward muon bundle event, several dozens of PeV muons at angles ($\theta >> 5^o - 7^o$), reaching above the horizons, might be relics of a hadron UHECR event originated on inclined-horizons, hundreds kilometer away.

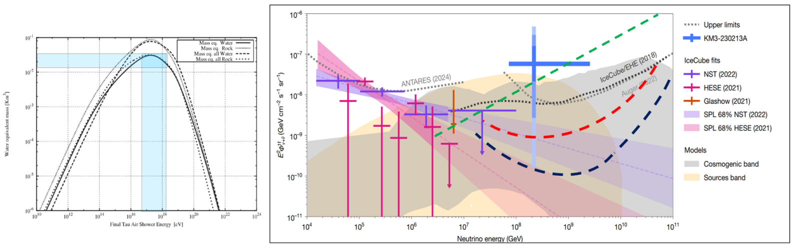

Figure 6: On the left the detector mass, in km^3 water equivalent, for each km^2 area in AUGER [4]. On the right, the averaged EeV neutrino event by ARCA ,within previous spectra data and bounds, following [34]. We underline, in partial disagreement with their figure above, that the AUGER bound in shouldbe more effective and more severe than their gray dot curve. :At EeV energy, at least three or four times than ICECUBE one, even considering the night 10% reduction for telescopes. Therefore the curve on the left is transferred as a more restrictive bound (dashed red line) on the right. The united ICECUBE and the AUGER limit is shown by a lower dashed black curve. One note that the ARCA spectra tendency in present figure shows a trend (dashed green line) to even a larger flux at ZeV energy. Ideal and tuned for Z- Boson model [41]. Recent UHECR could be quite successful correlated with a dozen of Local Sheet AGN sources [25]. However rare UHECR event clustering, with far AGN as 3C 454 may need such ZeV neutrino courier. [25].

3.1 A speculative Conclusion : an exciting options

If the ARCA EeV neutrino event is more verified and confirmed as a real one, it might skipped to wider ICECUBE detector discovery because of their severe filtering of very horizontal arrival directions, to avoid atmospheric noises. The AUGER array detector , three-four times more capable in the EeV energy windows, could not observe such an up-going air-shower if their real extreme energy is above tens of EeV energy. Indeed, such extreme neutrino energy $E_\tau > 10^{19} eV$, will produce a decay distance too far τ: $(D_\tau > 500 km \cdot (E_\tau/(10 EeV)))$. : the only surviving events will be very horizontal. Their decay will be extremely far , at high, rarefied altitudes . These levels of diluted atmosphere are so low that the consequent airshower slant depth is not large enough to form bright fluorescence light , easily observed. This energy will be an opportunity for different tuned theoretical model to revive and confirm. The tuned energetic neutrino events at highest , ZeV, 10^{21} eV energy , are a necessary and required tool in the Z-Burst model. Model suitable for solving some rare UHECR puzzles. Better studies on ICECUBE horizontal muons should reveal such rare signals. Anyway, AUGER array might better review their up-going air-shower signatures. Such a Z-Burst model is capable of explaining far (above GZK) UHECR arrival sources by their scattering onto our dark matter galactic relic neutrino halo, with $0.1 - 0.4$ eV mass, in extended Mpc halos. Time and wider detectors would confirm, with any additional events, also based also on tau air-showers, the nature of such exciting EeV neutrino astronomy. No new signal would slowly favor the inclined array, which misled the interpretation of the ARCA event. More EeV neutrino signals, their mass splitting combined with UHECR spectra bumps and clustering, might offer a road map to revolutionary neutrino mass spectroscopy [42] .

3.2 Dedication

The present article is dedicated to the tau discovery by M.Perl half century ago, to the energy conservation theorem by Emmy Noether more than a century ago, to the nuclear fission understanding by Lisa Meitner, to the proposal of a neutrino mixing by Bruno Pontecorvo, and in a Jewish humorist letter, the sudden vision for an invisible neutrino, by Wolfgang Pauli .

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