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ULTRA HIGH ENERGY COSMIC RAY and UHE ν-ν_r-Z Showering IN DARK HALOS

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ABSTRACT. The Ultra High Energy Cosmic Ray (UHECR), by ν_r-Z showering in Hot Dark Halos (HDM), shows an energy spectra, an anisotropy following the relic neutrino masses and clustering in dark halo. The lighter are the relic ν masses, the higher their corresponding Z resonance energy peaks. A *twin* light neutrino mass splitting may reflect a *twin* Z resonance and a complex UHECR spectra modulation (*a twin*) bump at highest GZK energy cut-off. Each possible ν mass associates a characteristic dark halo size (galactic, local, super cluster) and its anisotropy due to our peculiar position within that dark matter distribution. The expected Z or WW,ZZ showering into $p\ \bar{p}$ and $n\ \bar{n}$ should correspond to peculiar clustering in observed UHECR at 10^{19},$2\cdot10^{19}$, $4\cdot10^{19}$. A ν HDM halo around a Mpc will allow to the UHECR $n\ \bar{n}$ secondary component at $E_n > 10^{20}$ eV (due to Z decay) to arise playing a role comparable with the charged $p\ \bar{p}$ ones. Their un-deflected $n\ \bar{n}$ flight is shorter leading to a prompt and hard UHECR trace pointing toward the original UHECR source direction. The direct $p\ \bar{p}$ pairs are split and spread by random magnetic fields into a more diluted and smeared and lower energy UHECR signal around the original source direction. Additional prompt TeVs signals by synchrotron radiation of electro-magnetic Z showering must also occur solving the Infrared-TeV cut-off. The observed hard doublet and triplets spectra, their time and space clustering already favor the rising key role of UHECR $n\ \bar{n}$ secondaries originated by ν-Z tail shower.

1. Introduction

Light Neutrino may play a relevant role in Hot Dark Matter models within a hot-cold dark matter (HCDM) scenario. Their clustering in Galactic, Local dark halos offer the possibility to overcome the Cosmic Black Body opacity ($\gtrsim 4\cdot10^{19}\,eV$) (GZK) at highest energy cosmic ray astrophysics. These rare events almost in isotropic spread are probably originated by blazars AGN, QSRs in standard scenario, and they should not come, if originally of hadronic nature, from large distances (above tens Mpcs) because of the electro-magnetic dragging friction of cosmic 2.75 K BBR and of the inter-galactic radio backgrounds (GZK cut-off). Indeed as noted by Greisen, Zatsepin and Kuzmin (K.Greisen 1966, Zat'sepin 1966), proton and nucleon mean free path at E $> 5\cdot10^{19}\,EeV$ is less than 30 Mpc and asymptotically nearly ten Mpc.; also gamma rays at those energies have even shorter interaction length ($10\,Mpc$) due to severe opacity by electron pair production via microwave and radio background interactions (R.J.Protheroe 1997). Nevertheless these powerful sources (AGN, Quasars, GRBs) suspected to be the unique source able to eject such UHECRs, are rare at nearby distances ($\lesssim 10 \div 20\,Mpc$, as for nearby $M87$ in Virgo cluster); moreover there are not nearby AGN in the observed UHECR arrival directions. Strong and coherent galactic(R.J.Protheroe 1997) or extra-galactic (Farrar et all. 2000) magnetic fields, able to bend such UHECR (proton, nuclei) directions are not really at hand. The needed coherent lengths and strength are not easily compatible with known cosmic magnetic fields. Finally in this scenario the ZeV neutrons born, by photo-pion proton conversions on BBR, may escape the magnetic fields bending and should keep memory of the arrival direction, leading to (unobserved) clustering toward the primary source. Secondaries EeV photons (by neutral pion decays) should also abundantly point and cluster toward the same nearby AGN sources (P.Bhattacharjee 2000, Elbert et all. 1995) contrary to $AGASA$ data. Another solution of the present GZK puzzle, the Topological defects (TD), assumes as a source, relic heavy particles of early Universe; they are imagined diffused as a Cold Dark Matter component, in galactic or Local Group Halos. Nevertheless the TD fine tuned masses and ad-hoc decays are unable to explain the growing evidences of doublets and triplets clustering in $AGASA\;\;UHECR$ arrival data. On the other side there are growing evidences of self-correlation between UHECR arrival directions with far Compact Blazars at cosmic distance well above GZK cut-off (Tinyakov P.G.et Tkachev 2001). Therefore the solution of UHECR puzzle based on primary Extreme High Energy (EHE) neutrino beams (from AGN) at ZeV $E_\nu > 10^{21}$ eV and their undisturbed propagation from cosmic distances up to nearby calorimeter (made by relic light ν in dark galactic or local dark halo (Fargion et Salis 1997, Fargion, Mele et Salis 1999, Weiler 1999, Yoshida et all. 1998) is still, the most favorite convincing solution for the GZK puzzle. New complex scenarios for each neutrino mass spectra are then opening and important signature of UHECR Z,WW showering must manifest in observed anisotropy and space-time clustering.

2. Relic ν_r neutrino masses and Hot Halo Clustering

If relic neutrinos have a mass larger than their thermal energy ($1.9\;K^0$) they may cluster in galactic or Local Group halos; at eVs masses the clustering seem very plausible and it may play a role in dark hot cosmology(Fargion 1983). Their scattering with incoming extra-galactic EHE neutrinos determine high energy particle cascades which could contribute or dominate the observed UHECR flux at GZK edges. Indeed the possibility that neutrino share a little mass has been reinforced by Super-Kamiokande evidence for atmospheric neutrino anomaly via $\nu_\mu \leftrightarrow \nu_\tau$ oscillation. An additional evidence of neutral lepton flavour mixing has been very recently reported also by Solar neutrino experiment (SNO,Gallex,K2K). Consequently there are at least two main extreme scenario for hot dark halos: either ν_μ , ν_τ are both extremely light ($m_{\nu_\mu} \sim m_{\nu_\tau} \sim \sqrt{(\Delta m)^2} \sim 0.05\,eV$) and therefore hot dark neutrino halo is very wide, smeared and spread out to local group clustering sizes (increasing the radius but loosing in the neutrino density clustering contrast), or ν_μ, ν_τ may share degenerated (eV masses) split by a very tiny different values.

In the latter fine-tuned neutrino mass case ($m_\nu \sim 0.4eV - 1.2eV$) (see Fig,2 and Fig.3) the Z peak $\nu\bar{\nu}_r$ interaction (Fargion et Salis 1997, Fargion, Mele et Salis 1999, Weiler 1999, Yoshida et all. 1998) will be the favorite one; in the second case (for heavier non constrained neutrino mass ($m_\nu \gtrsim 3\,eV$)) only a $\nu\bar{\nu}_r \rightarrow W^+W^-$(Fargion et Salis 1997, Fargion, Mele et Salis 1999), and the additional $\nu\bar{\nu}_r \rightarrow ZZ$ interactions, (see the cross-section in Fig.1)(Fargion et all. 2001) considered here will be the only ones able to solve the GZK puzzle. Indeed the relic neutrino mass within HDM models in galactic halo near $m_\nu \sim 4eV$, corresponds to a lower and Z resonant incoming energy

$$E_\nu = \left(\frac{4eV}{\sqrt{{m_\nu}^2 + p_\nu^2}} \right) \cdot 10^{21}\,eV. \qquad (1)$$

This resonant incoming neutrino energy is unable to overcome GZK energies while it is showering mainly a small energy fraction into nucleons ($p, \bar{p}, n, \bar{n}$), (see $Tab.1$ below), at energies E_p quite below. (see $Tab.2$ below).

$$E_p = 2.2 \left(\frac{4eV}{\sqrt{{m_\nu}^2 + p_\nu^2}} \right) \cdot 10^{19}\,eV. \qquad (2)$$

Therefore too heavy ($> 1.5eV$) neutrino mass are not fit to solve GZK by Z-resonance; on the contrary WW,ZZ showering as well as t-channel showering may naturally keep open the solution. In particular the overlapping of both the Z and the WW, ZZ channels described in fig.1, for $m_\nu \simeq 2.3eV$ while solving the UHECR above GZK they must pile up (by Z-resonance peak activity) events at $5 \cdot 10^{19}eV$, leading to a bump in AGASA data. There is indeed a first marginal evidence of such a UHECR bump in AGASA and Yakutsk data that may stand for this interpretation. More detailed data are needed to verify such very exciting possibility. Similar result regarding the fine tuned relic mass at $0.4eV$ and $2.3eV$, (however ignoring the WW ZZ and t-channels and invoking very hard UHE neutrino spectra) have been independently reported recently (Fodor et all. 1999) . Most of us consider cosmological light relic neutrinos in Standard Model at non relativistic regime neglecting any relic neutrino momentum p_ν term. However, at lightest mass values the momentum may be comparable to the relic mass; moreover the spectra may reflect additional relic neutrino-energy injection which are feeding standard cosmic relic neutrino at energies much above the same neutrino mass. Indeed there may exist, within or beyond Standard Cosmology, a relic neutrino component due to stellar, Super Nova, GRBs, AGN past activities, presently red-shifted into a KeV-eV spectra, piling into a relic neutrino grey-body spectra. Therefore it is worth-full to keep the most general mass and momentum term in the target relic neutrino spectra. In this windy ultra-relativistic neutrino cosmology, eventually leading to a neutrino radiation dominated Universe, the halo size to be considered is nearly coincident with the GZK one defined by the energy loss lenght for UHECR nucleons ($\sim 20Mpcs$). Therefore the isotropic UHECR behaviour is guaranteed but a puzzle related to uniform source distribution seem to persist. Nevertheless the UHE neutrino- relic neutrino scattering *do not* follow a flat spectra as shown in figure 2, (as well as any hypothetical ν grey body spectra). This leave open the opportunity to have a relic relativistic neutrino component

Secondaries by $\nu\nu \to Z$ Interactions: $E_\nu = 10^{22} eV$, Fluence $F_\nu = 2000 eV cm^{-2} s^{-1}$, $(m_\nu = 0.4\ eV)$					
	Multiplicity	Energy (%)	$\sum E_{CM}(GeV)$	Peak Energy (EeV)	$\frac{dN}{dE}E^2$ (eV)
p	2.7	6 %	5.4	$2.2 \cdot 10^2$	1.2
π_0	13	21.4 %	19.25	$1.9 \cdot 10^2$	4.25
γ_{π^0}	26	21.4 %	19.25	95	4.25
$\pi^\pm$	26	42.8 %	38.5	$1.9 \cdot 10^2$	4.25
$(e^+e^-)_\pi$	26	12 %	11	50	2.3
$(e^+e^-)_{prompt}$	2	3.3 %	2.7	$5 \cdot 10^3$	1.32
$(e^+e^-)_\mu$	2	1.1 %	0.9	$1.6 \cdot 10^3$	0.45
$(e^+e^-)_\tau$	2	1.5 %	1.3	$1.2 \cdot 10^3$	0.6

Fig. 1. Table 1A: The detailed energy percentage distribution into neutrino, protons, neutral and charged pions and consequent gamma, electron pair particles both from hadronic and leptonic Z, WW, ZZ channels. We calculated the elecro-magnetic contribution due to the t-channel $\nu_i\nu_j$ interactions. We used LEP data for Z decay and considered W decay roughly in the same way as Z one. We assumed that an average number of 37 particles is produced during a Z (W) hadronic decay. The number of prompt pions both charged (18) and neutral (9), in the hadronic decay is increased by 8 and 4 respectively due to the decay of K^0, $K^\pm$, ρ, ω, and η particles. (*)We assumed that the most energetic neutrinos produced in the hadronic decay mainly come from charged pion decay. So their number is roughly three times the number of π's. UHE photons are mainly relics of neutral pions. Most of the γ radiation will be degraded around PeV energies by $\gamma\gamma$ pair production with cosmic 2.75 K BBR, or with cosmic radio background. The electron pairs instead, are mainly relics of charged pions and will rapidly lose energies into synchrotron radiation. The contribution of leptonic Z (W) decay is also considered and calculated in the table above and below.

at eVs energies as well as the observed non uniform UHECR spectra. This case is similar to the case of a very light neutrino mass much below 0.1 eV. As we noticed above, relic neutrino mass above a few eVs in HDM halo *are not* consistent with naive Z peak; higher energies interactions ruled by WW,(D.Fargion, B.Mele et A.Salis 1999; K.Enqvist et all. 1989) ZZ cross-sections (Fargion 2001) may nevertheless solve the GZK cut-off. In this regime there will be also possible to produce by virtual W exchange, t-channel, UHE lepton pairs, by $\nu_i\bar{\nu}_j \to l_i\bar{l}_j$, leading to additional electro-magnetic showers injection.
As we shall see these important and underestimated signal will produce UHE electrons whose final trace are TeVs synchrotron photons able to break the IR-TeV cosmic cut-off. The hadronic tail of the Z or W^+W^- cascade maybe the source of final nucleons $p, \bar{p}, n, \bar{n}$ able to explain UHECR events observed by Fly's Eye and AGASA (Y.Uchihori et al. 2000) and other detectors. The same $\nu\bar{\nu}_r$ interactions are source of Z and W that decay in rich shower ramification. The average energy deposition for both gauge bosons among the secondary particles is summarized in Table 1A below.

3. UHECR channels in Z showers

Although protons (or anti-protons) are the most popular and favorite candidate in order to explain the highest energy air shower observed, one doesn't have to neglect the signature of final neutron and anti-neutrons as well as electrons and photons. Indeed the

UHECR neutrons are produced in Z-WW showering at nearly same rate as the charged nucleons. Above GZK cut-off energies UHE n,$\bar{n}$, share a life lenght comparable with the Hot Galactic Dark Neutrino Halo. Therefore they may be an important component in UHECRs. Moreover prompt UHE electron (positron) interactions with the galactic or extra-galactic magnetic field or soft radiative backgrounds may lead to gamma cascades and from PeVs to TeVs energies.
Gamma photons at energies $E_\gamma \simeq 10^{20}$ - $10^{19}\,eV$ may freely propagate through galactic or local halo scales (hundreds of kpc to few Mpc) and could also contribute to the extreme edges of cosmic ray spectrum and clustering (Yoshida et al. 1998, Fargion et al. 2001).
The ratio of the final energy flux of nucleons near the Z peak resonance, Φ_p over the corresponding electro-magnetic energy flux Φ_{em} ratio is, as in tab.1 e^+e^-,γ entrance, nearly $\sim \frac{1}{8}$. Moreover if one considers at higher E_ν energies, the opening of WW, ZZ channels and the six pairs $\nu_e\bar{\nu_\mu}$, $\nu_\mu\bar{\nu_\tau}$, $\nu_e\bar{\nu_\tau}$ (and their anti-particle pairs) t-channel interactions leading to highest energy leptons, with no nucleonic relics (as $p, \bar{p}$), this additional injection favors the electro-magnetic flux Φ_{em} over the corresponding nuclear one Φ_p by a factor ~ 1.6 leading to $\frac{\Phi_p}{\Phi_{em}} \sim \frac{1}{13}$. This ratio is valid at WW, ZZ masses because the overall cross section variability is energy dependent. At center of mass energies above these values, the $\frac{\Phi_p}{\Phi_{em}}$ decreases more because the dominant role of t-channel (Fig1). We focus here on Z, and WW,ZZ channels showering in hadrons for GZK events. The important role of UHE electron showering into TeV radiation is discussed below.

There is an upper bound density clustering for very light Dirac fermions due to the maximal Fermi degenerancy whose adimensional density contrast is $\delta\rho \propto m_\nu^3$, while one finds (Fargion 1983) that the neutrino free-streaming halo grows only as $\propto m_\nu^{-1}$. Therefore the overall interaction probability grows $\propto m_\nu^2$, favoring heavier non relativistic (eVs) neutrino masses. In this frame above few eV neutrino masses only WW-ZZ channel are operative. Nevertheless the same lightest relic neutrinos may share higher Local Group velocities (thousands $\frac{Km}{s}$) or even nearly relativistic speeds and it may therefore compensate the common density bound:

$$n_{\nu_i} = 1.9 \cdot 10^3 \left(\frac{m_i}{0.1eV}\right)^3 \left(\frac{v_{\nu_i}}{2 \cdot 10^3 \frac{Km}{s}}\right)^3 \tag{3}$$

From the cross section side there are three main interaction processes that have to be considered leading to nucleons in the of EHE and relic neutrinos scattering.

channel 1. The $\nu\nu_r \to Z \to$ annihilation at the Z resonance.

channel 2. $\nu_\mu\bar{\nu_\mu} \to W^+W^-$ or $\nu_\mu\bar{\nu_\mu} \to ZZ$ leading to hadrons, electrons, photons, through W and Z decay.

channel 3. The ν_e - $\bar{\nu_\mu}$, ν_e - $\bar{\nu_\tau}$, ν_μ - $\bar{\nu_\tau}$ and antiparticle conjugate interactions of different flavor neutrinos mediated in the t-channel by the W exchange (i.e. $\nu_\mu\bar{\nu_{\tau_r}} \to \mu^-\tau^+$). These reactions are sources of prompt and secondary UHE electrons as well as photons resulting by hadronic τ decay.

Their cross-section values are plotted in Fig.1. The asymptotic behaviour of these cross section is proportional to $\sim (\frac{M_W^2}{s}) \ln(\frac{s}{M_W^2})$ for $s \gg M_Z^2$.

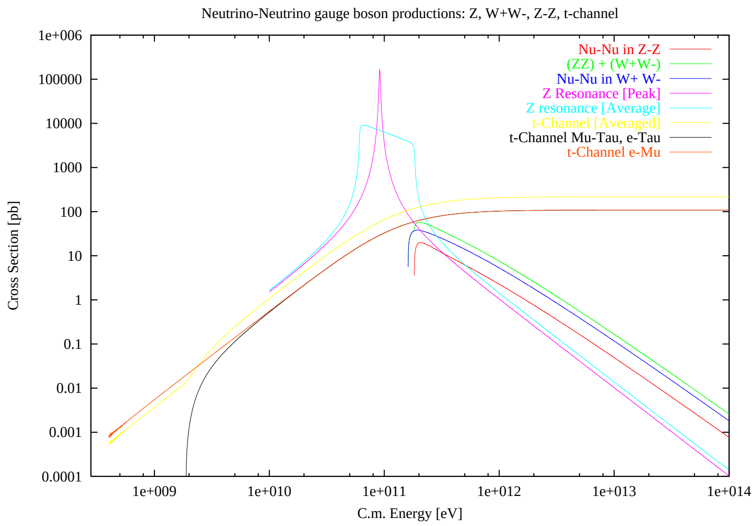

Fig. 2. The $\nu\bar{\nu} \to Z, W^+W^-, ZZ, T$-channel, cross sections as a function of the center of mass energy in $\nu\nu$. These cross-sections are estimated also in average (Z) as well for each possible t-channel lepton pairs. The averaged t-channel averaged the multiplicity of flavours pairs ν_i, $\bar{\nu}_j$ respect to neutrino pair annihilations into Z neutral boson. The Z-WW-ZZ Showering has to be relativistically boosted to show their behaviour at laboratory system.

The nucleon arising from WW and ZZ hadronic decay could provide a reasonable solution to the UHECR events above GZK. We'll assume that the fraction of pions and nucleons related to the total number of particles from the W boson decay is the almost the same of Z boson. So W hadronic decay ($P \sim 0.68$) leads on average to about 37 particles, where $< n_{\pi^0} >\sim 9.19$, $< n_{\pi^\pm} >\sim 17$, and $< n_{p,\bar{p},n,\bar{n}} >\sim 2.7$. In addition we have to expect by the subsequent decays of π's (charged and neutral), kaons and resonances (ρ, ω, η) produced, a flux of secondary UHE photons and electrons. As we already pointed out, the particles resulting from the decay are mostly prompt pions. The others are particles whose final decay likely leads to charged and neutral pions as well. As a consequence the electrons and photons come from prompt pion decay. On average it results (Fargion, Grossi et Lucentini 2001; Fargion, Grossi, Lucentini et Troia 2001) that the energy in the bosons decay is not uniformly distributed among the particles. Each charged pion will give an electron (or positron) and three neutrinos, that will have less than one per cent of the initial W boson energy, while each π^0 decays in two photons, each with 1 per cent of the initial W energy. In the Table 1A above we show all the channels leading from single Z,W and Z pairs as well as t-channel in nuclear and electro-magnetic components.

This interactions, as noted in Table 1A are leading to electro-magnetic showers and are not offering any nuclear secondary.

4. The Boosted Z-UHECR spectra

Let us examine the destiny of UHE primary particles (nucleons, electrons and photons) ($E_e \lesssim 10^{21}\, eV$) produced after hadronic or leptonic W decay. As we already noticed in the introduction, we'll assume that the nucleons, electrons and photons spectra (coming from W or Z decay) after $\nu\nu$ scattering in the halo, follow a power law that in the center of mass system is $\frac{dN^*}{dE^* dt^*} \simeq E^{*-\alpha}$ where $\alpha \sim 1.5$. This assumption is based on detailed Monte Carlo simulation of a heavy fourth generation neutrino annihilations(Yu. A.Golubkov 1998; D. Fargion,Yu.A.Golubkov, M.Yu.Khlopov 1999; D. Fargion, R. Konoplich et all. 2000) and with the model of quark - hadron fragmentation spectrum suggested by Hill (C.T.Hill 1983).

In order to determine the shape of the particle spectrum in the laboratory frame, we have to introduce the Lorentz relativistic transformations from the center of mass system to the laboratory system. The number of particles is clearly a relativistic invariant $dN_{lab} = dN^*$, while the relation between the two time intervals is $dt_{lab} = \gamma dt^*$, the energy changes like $\epsilon_{lab} = \gamma \epsilon^*(1 + \beta \cos\theta^*) = \epsilon^* \gamma^{-1}(1 - \beta\cos\theta)^{-1}$, and finally the solid angle in the laboratory frame of reference becomes $d\Omega_{lab} = \gamma^2 d\Omega^*(1 - \beta\cos\theta)^2$. Substituting these relations one obtains

$$\left(\frac{dN}{d\epsilon dt d\Omega}\right)_{lab} = \frac{dN_*}{d\epsilon_* dt_* d\Omega_*}\gamma^{-2}(1 - \beta\cos\theta)^{-1} =$$

$$= \frac{\epsilon_*^{-\alpha}\ \gamma^{-2}}{4\pi} \cdot (1 - \beta\cos\theta)^{-1} = \frac{\epsilon^{-\alpha}\ \gamma^{-\alpha-2}}{4\pi}(1 - \beta\cos\theta)^{-\alpha-1} \tag{4}$$

and integrating on θ (omitting the lab notation) one loses the spectrum dependence on the angle.

The consequent fluence derived by the solid angle integral is:

$$\frac{dN}{d\epsilon dt}\epsilon^2 = \frac{\epsilon^{-\alpha+2}\ \gamma^{\alpha-2}}{2\beta\alpha}[(1+\beta)^\alpha - (1-\beta)^\alpha] \simeq \frac{2^{\alpha-1}\epsilon^{-\alpha+2}\ \gamma^{\alpha-2}}{\alpha} \tag{5}$$

There are two extreme case to be considered: the case where the interaction occurs at Z peak resonance and therefore the center of mass Lorents factor γ is frozen at a given value (eq.1) and the case (WW,ZZ pair channel) where all energies are allowable and γ is proportional to $\epsilon^{1/2}$. Here we focus only on Z peak resonance. The consequent fluence spectra $\frac{dN}{d\epsilon dt}\epsilon^2$, as above, is proportional to $\epsilon^{-\alpha+2}$. Because α is nearly 1.5 all the consequent secondary particles will also show a spectra proportional to $\epsilon^{1/2}$ following a normalized energies shown in Tab.2, as shown in Fig.(2-6). In the latter case (WW,ZZ pair channel), the relativistic boost reflects on the spectrum of the secondary particles, and the spectra power law becomes $\propto \epsilon^{\alpha/2+1} = \epsilon^{0.25}$. These channels will be studied in details elsewhere. In Fig. 1 we show the spectrum of protons, photons and electrons coming from Z hadronic and leptonic decay assuming a nominal primary CR energy flux $\sim 20\ eV s^{-1} sr^{-1} cm^{-2}$, due to the total $\nu\bar{\nu}$ scattering at GZK energies as shown in figures 2-6. Let us remind that we assume an interaction probability of $\sim 1\%$ and a corresponding UHE incoming neutrino energy $\sim 2000\ eV s^{-1} sr^{-1} cm^{-2}$ near but below present UHE neutrino flux bound from AMANDA and Baikal as well as Goldstone data.

Secondaries Energy Distributions In Z Decay ($m_\nu = 0.4\ eV$)		
Channel	$E(eV)$	$\frac{dN}{dE}E^2$ (eV)
p	$2.2 \cdot 10^{20}$	1.2
γ	$9.5 \cdot 10^{19}$	4.25
e_π	$5 \cdot 10^{19}$	2.3
e_{prompt}	$5 \cdot 10^{21}$	1.32
e_μ	$1.66 \cdot 10^{21}$	0.45
e_τ	$1.2 \cdot 10^{21}$	0.6

TABLE I

B. Summary of Energy peak and Energy Fluence for different decay channels as described in Table 1A to build up the Fig.1; $m_\nu = 0.4eV$

5. The UHECRs from Relic ν Masses

The role of each relic neutrino mass is summirized from the convolutions of the UHE neutrino spectra with the relic neutrino mass, its density as well as the cross-sections described above. The case of Z-resonance event with a single neutrino mass has a narrow fine tuned energy mass windows (0.4 eV-1.2 eV) described respectively in Figures 3-4.

We remind again that a heavier neutrino mass ($\geq 2eVs$) imply the rise of WW-ZZ channels and a pile up of Z resonance cross-section at lower UHECR spectra. This feature maybe already responsible for the tiny bump in observed events around $5 \cdot 10^{19}eV$. The lighter neutrino mass possibilities (near 0.1 eV) are comparable with present Super-Kamiokande atmospheric neutrino mass and are leading to the exciting scenario where more non degenerated Z-resonances occur (Fargion 2001). These scenario are summarized in Fig. 5 (for nominal example $m_{\nu_\tau} = 0.1$ eV; $m_{\nu_\mu} = 0.05$ eV). The twin neutrino mass inject a corresponding twin bump at highest energy. Another limiting case of interest takes place when the light neutrino masses are extreme, nearly at atmospheric (SK,K2K) and solar (SNO) neutrino masses. This case is described in two different versions in Fig.6 (assuming comparable neutrino densities) and Fig.7 (keeping care of the lightest neutrino density diluitions). The relic neutrino masses are assumed $m_{\nu_\tau} = 0.05$ eV; $m_{\nu_\mu} = 0.001$ eV). A more complex scenario is also possible when it takes place both a narrow twin bump (Fig5) *and* a wider twin bump (Fig 6-7) because of a small neutrino tau-muon mass splitting overlapping with a wider one due to lightest neutrino electron mass.

6. UHECRs Clustering and Anisotropy

The neutrino mass play a role in defining its Hot Dark Halo size and the consequent enhancement of UHECR arrival directions due to our peculiar position in the HDM

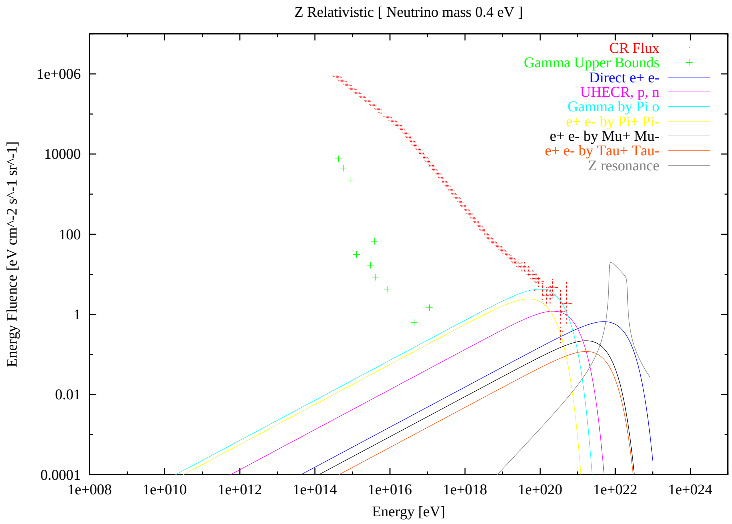

Fig. 3. Energy Fluence derived by $\nu\bar{\nu} \to Z$ and its showering into different channels: direct electron pairs UHECR nucleons n p and anti-nucleons, γ by π^0 decay, electron pair by $\pi^+\pi^-$ decay, electron pairs by direct muon and tau decays as labeled in figure. The relic neutrino mass has been assumed to be fine tuned to explain GZK UHECR tail: $m_\nu = 0.4eV$. The Z resonance ghost (the shadows of Z Showering resonance (Fargion 2001) curve), derived from Z cross-section in Fig.1, shows the averaged Z resonant cross-section peaked at $E_\nu = 10^{22}eV$. Each channel shower has been normalized following table 1B.

halo. Indeed for a heavy $\geq 2eV$ mass case HDM neutrino halo are mainly galactic and/or local, reflecting an isotropic or a diffused amplification toward nearby $M31$ HDM halo. In the lighter case the HDM should include the Local Cluster up to Virgo. To each size corresponds also a different role of UHECR arrival time. The larger the HDM size the longer the UHECR random-walk travel time (in extra-galactic random magnetic fields) and the wider the arrival rate lag between doublets or triplets. The smaller is the neutrino halo the earlier the UHE neutron secondaries by Z shower will play a role: indeed at $E_n = 10^{20}eV$ UHE neutron are flying a Mpc and their directional arrival (or their late decayed proton arrival) are more on-line toward the source. This may explain the high self collimation and auto-correlation of UHECR discovered very recently (Tinyakov et all. 2001). The UHE neutrons Z-Showering fits with the harder spectra observed in clustered events in AGASA (Takeda et all.2001). The same UHECR alignment may explain the quite short (2-3 years)(Takeda 2001) lapse of time observed in AGASA doublets. Indeed the most conservative scenario where UHECR are just primary proton from nearby sources at GZK distances (tens of Mpcs) are no longer acceptable either because the absence of such nearby sources and because of the observed stringent UHECR clustering $(2^o - 2.5^o)$ (Takeda et all. 2001) in arrival direction, as well as because of the short (~ 3 years) characteristic time lag between clustered events. Finally the same growth with energy of UHECR neutron (and anti-neutron) life-lengths

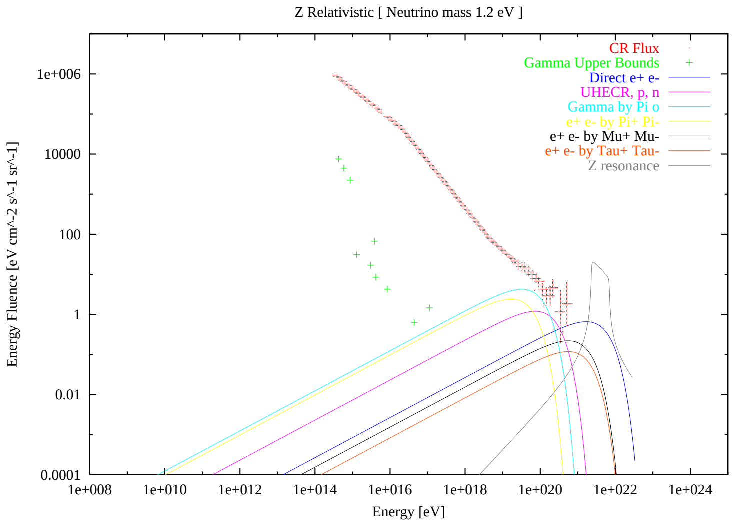

Fig. 4. Energy Fluence derived by $\nu\bar{\nu} \to Z$ and its showering into different channels as in previous Figure 2: direct electron pairs UHECR nucleons n p, γ by π^0 decay, electron pair by $\pi^+\pi^-$ decay, electron pairs by direct muon and tau decays as labeled in figure. In the present case the relic neutrino mass has been assumed to be fine tuned to explain GZK UHECR tail: $m_\nu = 1.2eV$ with the same UHE incoming neutrino fluence of previous figure. The Z resonance curve shows the averaged Z resonant cross-section peaked at $E_\nu = 3.33 \cdot 10^{21} eV$.Each channel shower has been normalized in analogy to table 1B.

(while being marginal or meaning-less in tens Mpcs GZK flight distances) may naturally explain, within a $\sim Mpc$ Z Showering Neutrino Halo, the arising harder spectra revealed in doublets-triplet spectra (Aoki et all. 2001).

7. The apparent Tinyakov-Glushkov Paradox

The same role of UHE neutron secondaries from Z showering in HDM halo may also solve an emerging puzzle: the correlations of arrival directions of UHECRs found recently (Glushkov et all. 2001) in Yakutsk data at energy $E = 8 \cdot 10^{18} eV$ toward the Super Galactic Plane are to be compared with the compelling evidence of UHECRs events ($E = 3 \cdot 10^{19} eV$ above GZK) clustering toward well defined BL Lacs at cosmic distances (redshift $z > 0.1 - 0.2$) (Tinyakov et Tkachev 2001; Tinyakov et al. 2001). Where is the real UHECR sources location? At Super-galactic disk (50 Mpcs wide, within GZK range) or at cosmic ($\geq 300 Mpcs$) edges? It should be noted that even for the Super Galactic hypothesis (Glushkov et all. 2001) the common proton are unable to justify the high collimation of the UHECR events. Of course both results (or just one of them) maybe a statistical fluctuation. But both studies seem statistically significant (4.6-5 sigma) and they seem in obvious disagreement. There may be still open the possibility of *two* new categories of UHECR sources both of them located at different distances above GZK

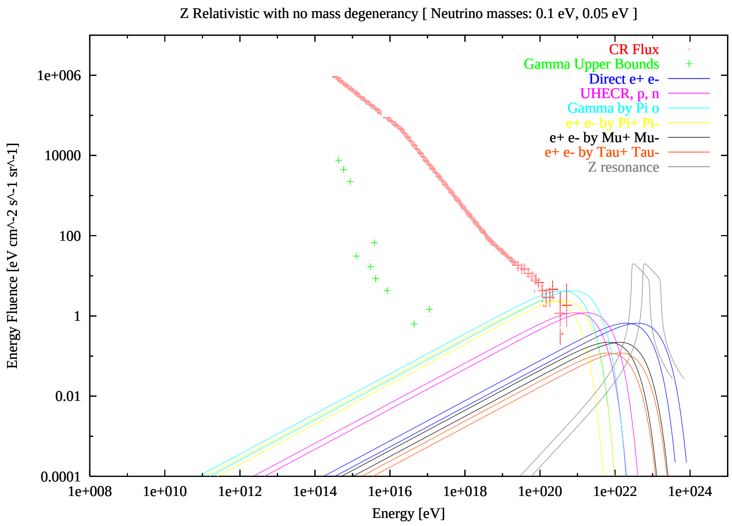

Fig. 5. Energy Fluence derived by $\nu\bar{\nu} \rightarrow Z$ and its showering into different channels: direct electron pairs UHECR nucleons n p, γ by π^0 decay, electron pair by $\pi^+\pi^-$ decay, electron pairs by direct muon and tau decays as labeled in figure. In the present case the relic neutrino masses have been assumed with no degenerancy. Their values have been fine tuned to explain GZK UHECR tail: $m_{\nu_1} = 0.1 eV$ and $m_{\nu_2} = 0.05 eV$. No relic neutrino density difference has been assumed. The incoming UHE neutrino fluence has been increased by a factor 2 respect previous Fig.3-4. The Z resonance curve shows the averaged Z resonant cross-section peaked at $E_{\nu_1} = 4 \cdot 10^{22} eV$ and $E_{\nu_2} = 8 \cdot 10^{22} eV$. Each channel shower has been normalized in analogy to table 1B.

ones (the harder the most distant BL Lac sources). But it seem quite unnatural the UHECR propagation by direct nucleons where the most distant are the harder. However our Z-Showering scenario offer different solutions: (1) The Relic Neutrino Masses define different Hierarchical Dark Halos and privileged arrival direction correlated to Hot Relic Neutrino Halos. The real sources are at (isotropic) cosmic edges (Tinyakov et Tkachev 2001; Tinyakov et al. 2001), but their crossing along a longer anisotropic relic neutrino cloud enhance the interaction probability in the Super Galactic Plane. (2) The nearest SG sources are weaker while the collimated BL Lacs are harder: both sources need a Neutrino Halo to induce the Z-Showering UHECRs. More data will clarify better the real scenario.

8. The TeV Tails from UHE electrons

As it is shown in Table 1A-B and Figures above, the electron (positron) energies by $\pi^\pm$ decays is around $E_e \sim 2 \cdot 10^{19} eV$ for an initial $E_Z \sim 10^{22} eV$ (and $E_\nu \sim 10^{22} eV$). Such electron pairs while not radiating efficently in extra-galactic magnetic fields will be interacting with the galactic magnetic field ($B_G \simeq 10^{-6} G$) leading to direct TeV

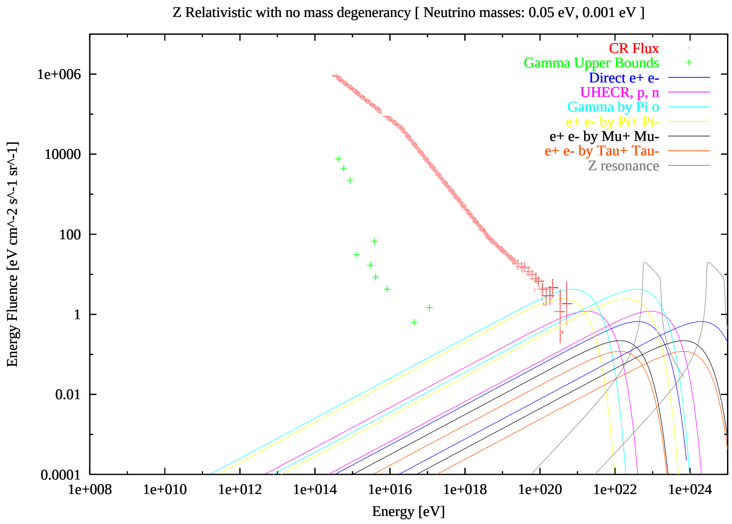

Fig. 6. Energy Fluence derived by $\nu\bar{\nu} \to Z$ and its showering into different channels as above. In the present extreme case the relic neutrino masses have been assumed with wide mass differences just compatible both with Super-Kamiokande and relic $2K^o$ Temperature. The their values have been fine tuned to explain observed GZK- UHECR tail: $m_{\nu_1} = 0.05 eV$ and $m_{\nu_2} = 0.001 eV$. No relic neutrino density difference between the two masses has been assumed, contrary to bound in eq.3. The incoming UHE neutrino fluence has been increased by a factor 2 respect previous Fig.2-3. The "Z resonance" curve shows the averaged Z resonant cross-section peaked at $E_{\nu_1} = 8 \cdot 10^{22} eV$ and $E_{\nu_2} = 4 \cdot 10^{24} eV$, just near Grand Unification energies. Each channel shower has been normalized in analogy to table 1B.

photons:

$$E_{\gamma}^{sync} \sim \gamma^2 \left(\frac{eB}{2\pi m_e}\right) \sim$$

$$\sim 27.2 \left(\frac{E_e}{2 \cdot 10^{19}\, eV}\right)^2 \left(\frac{m_\nu}{0.4\, eV}\right)^{-2} \left(\frac{B}{\mu G}\right) TeV. \tag{6}$$

The same UHE electrons will radiate less efficiently with extra- galactic magnetic field ($B_G \simeq 10^{-9}\, G$) leading also to direct peak 27.2 GeV photons. The spectrum of these photons is characterized by a power of law $dN/dEdT \sim E^{-(\alpha+1)/2} \sim E^{-1.25}$ where α is the power law of the electron spectrum, and it is showed in Figures above. As regards the prompt electrons at higher energy ($E_e \simeq 10^{21}\, eV$), in particular in the t-channels, their interactions with the extra-galactic field first and galactic magnetic fields later is source of another kind of synchrotron emission around tens of PeV energies E_{γ}^{sync}:

$$\sim 6.8 \cdot 10^{13} \left(\frac{E_e}{10^{21}\, eV}\right)^2 \left(\frac{m_\nu}{0.4\, eV}\right)^{-2} \left(\frac{B}{nG}\right) eV \tag{7}$$

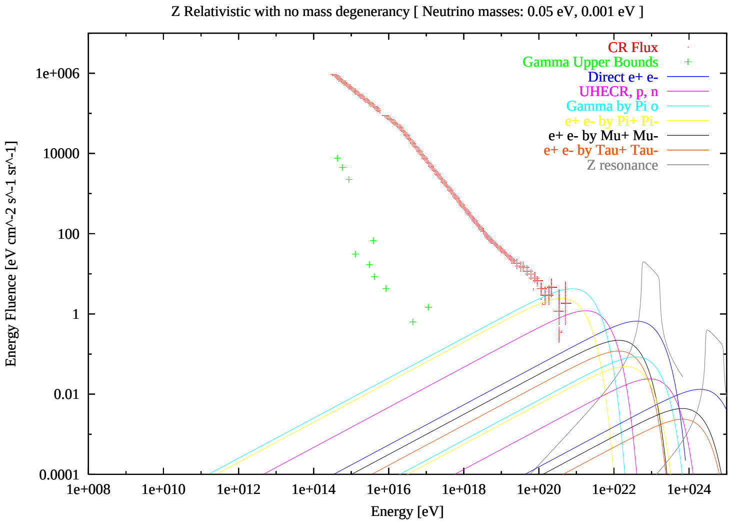

Fig. 7. Energy Fluence derived by $\nu\bar{\nu} \rightarrow Z$ and its showering into different channels as above. In the present extreme case the relic neutrino masses have been assumed with wide mass differences just compatible both with Super-Kamiokande and relic $2K^o$ Temperature. The their values have been fine tuned to explain observed GZK- UHECR tail: $m_{\nu_1} = 0.05 eV$ and $m_{\nu_2} = 0.001 eV$. A neutrino density difference between the two masses has been assumed,considering the lightest $m_{\nu_2} = 0.001 eV$ neutrino at relativistic regime, consistent to bound in eq.3. The incoming UHE neutrino fluence has been assumed growing linearly (Yoshida et all. 1998) with energy. Its value is increased by a factor 2 and 20 at $E_{\nu_1} = 8 \cdot 10^{22} eV$ and $E_{\nu_2} = 4 \cdot 10^{24} eV$ respect the previous ones Fig.2-3. The "Z resonance" curve shows its averaged Z resonant "ghost" cross-section peaked at $E_{\nu_1} = 2 \cdot 10^{23} eV$ and $E_{\nu_2} = 4 \cdot 10^{24} eV$, just near Grand Unification energies. Each channel shower has been normalized in analogy to table 1B.

$$\sim 6.8 \cdot 10^{16} \left(\frac{E_e}{10^{21}\, eV}\right)^2 \left(\frac{m_\nu}{0.4\, eV}\right)^{-2} \left(\frac{B}{\mu G}\right) eV \tag{8}$$

The corresponding energy loss length instead is (O.E.Kalashev, V.A.Kuzmin, D.V.Semikoz 2000)

$$\left(\frac{1}{E}\frac{dE}{dt}\right)^{-1} = 3.8 \times \left(\frac{E}{10^{21}}\right)^{-1} \left(\frac{B}{10^{-9} G}\right)^{-2} kpc. \tag{9}$$

For the first case the interaction lenght is few Kpcs while in the second one in few days light flight. Again one has the same power law characteristic of a synchrotron spectrum with index $E^{-(\alpha+1/2)} \sim E^{-1.25}$. Gammas at $10^{16} \div 10^{17}$ eV scatters onto low-energy photons from isotropic cosmic background $(\gamma + BBR \rightarrow e^+e^-)$ converting their energy in electron pair. The expression of the pair production cross-section is:

$$\sigma(s) = \frac{1}{2}\pi r_0^2 (1 - v^2)[(3 - v^4)\ln\frac{1+v}{1-v} - 2v(2 - v^2)] \tag{10}$$

where $v = (1-4m_e^2/s)^{1/2}$, $s = 2E_\gamma\epsilon(1-\cos\theta)$ is the square energy in the center of mass frame, ϵ is the target photon energy, r_0 is the classic electron radius, with a peak cross section value at

$$\frac{4}{137} \times \frac{3}{8\pi}\sigma_T \ln 183 = 1.2 \times 10^{-26}\, cm^2$$

Because the corresponding attenuation length due to the interactions with the microwave background is around ten kpc, the extension of the halo plays a fundamental role in order to make this mechanism efficient or not. As is shown in Fig.3-4, the contribution to tens of PeV gamma signals by Z (or W) hadronic decay, could be compatible with actual experimental limits fixed by CASA-MIA detector on such a range of energies. Considering a halo extension $l_{halo} \gtrsim 100kpc$, the secondary electron pair creation becomes efficient, leading to a suppression of the tens of PeV signal. So electrons at $E_e \sim 3.5 \cdot 10^{16}\, eV$ loose again energy through additional synchrotron radiation (O.E.Kalashev, V.A.Kuzmin, D.V.Semikozb 2000), with maximum E_γ^{sync} around

$$\sim 79 \left(\frac{E_e}{10^{21}\, eV}\right)^4 \left(\frac{m_\nu}{0.4\, eV}\right)^{-4} \left(\frac{B}{\mu G}\right)^3 MeV. \qquad (11)$$

Anyway this signal is not able to pollute sensibly the MeV-GeV; the relevant signal pile up at TeVs.

Gamma rays with energies up to 20 TeV have been observed by terrestrial detector only by nearby sources like Mrk 501 (z = 0.033) or very recently by MrK 421 (z = 0.031). More recent evidences of tens TeVs from (three times more) distant blazar 1ES1426+428 (z = 0.129) make even more dramatic the IR-TeV cut-off. This is puzzling because the extra-galactic TeV spectrum should be, in principle, significantly suppressed by the γ-rays interactions with the extra-galactic Infrared background, leading to electron pair production and TeVs cut-off. The recent calibration and determination of the infrared background by DIRBE and FIRAS on COBE have inferred severe constrains on TeV propagation. Indeed, as noticed by Kifune (Kifune 1997), and Protheroe and Meyer (Protheroe et Meyer 2000) we may face a severe infrared background - TeV gamma ray crisis. This crisis imply a distance cut-off, incidentally, comparable to the GZK one. Let us remind also an additional evidence for IR-TeV cut-off is related to the possible discover of tens of TeV counterparts of BATSE GRB970417, observed by Milagrito(R. Atkins et all. 2000), being most GRBs very possibly at cosmic edges, at distances well above the IR-TeV cut-off ones. In this scenario it is also important to remind the possibilities that the Fly's Eye event has been correlated to TeV pile up events in HEGRA (Horns et al. 1999). The very recent report (private communication 2001) of the absence of the signal few years later at HEGRA may be still consistent with a limited UHE TeV tail activity. To solve the IR-TeV cut-off one may alternatively invoke unbelievable extreme hard intrinsic spectra or exotic explanation as gamma ray superposition of photons or sacrilegious Lorentz invariance violation (G. Amelino-Camelia,et all 1998).

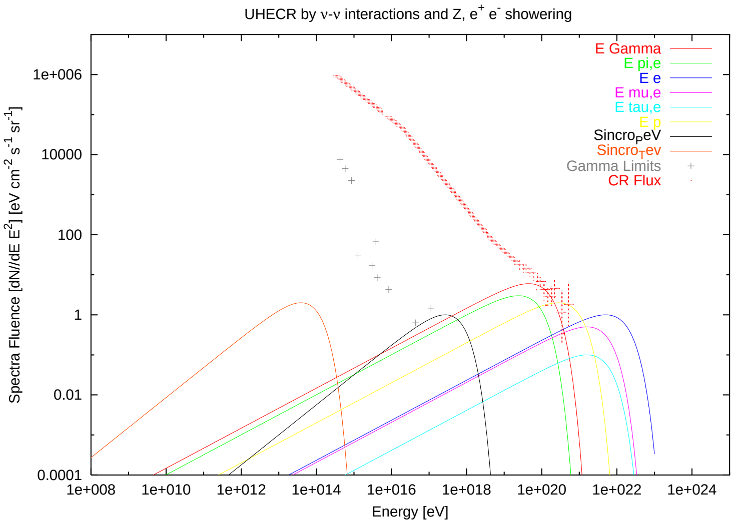

Fig. 8. Energy fluence by Z showering as in fig.3 for $m_\nu = 0.4eV$ and $E_\nu = 10^{22}eV$and the consequent e^+e^- synchrotron radiation by eq.16-18

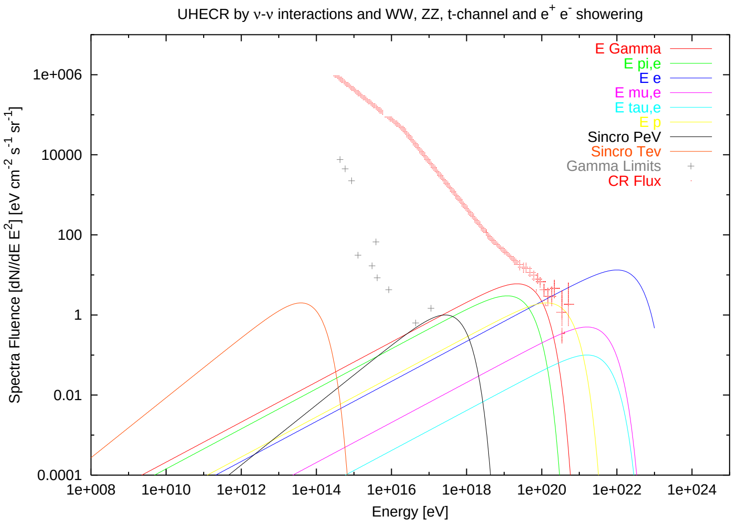

Fig. 9. Energy fluence by WW, ZZ, t-channel showering as in fig.3, for $m_\nu = 0.4eV$ and $E_\nu = 2 \cdot 10^{22}eV$, and the consequent e^+e^- synchrotron radiation by eq.16-18. The lower energy Z showering is not included to make spectra more understandable.

9. Conclusion

UHECR above GZK may be naturally born by UHE ν scattering on relic ones. The target cosmic ν may be light and dense as the needed ones in HDM model (few eVs). Then their W^+W^-, ZZ pair productions channel (not just the Z resonant peak) would solve the GZK puzzle. At a much lighter, but fine tuned case $m_\nu \sim 0.4eV$, $m_\nu \sim 1.5eV$ assuming $E_\nu \sim 10^{22}eV$, one is able to solve at once the known UHECR data at GZK edge by the dominant Z peak; in this peculiar scenario one may foresee (fig.2-3) a rapid decrease (an order of magnitude in energy fluence) above $3 \cdot 10^{20}eV$ in future data and a further recover (due to WW,ZZ channels) at higher energies. The characteristic UHECR fluxes will reflect the averaged neutrino-neutrino interactions shown in Fig.2-7. Their imprint could confirm the neutrino masses value and relic density. At a more extreme lighter neutrino mass, occurring for $m_\nu \sim m_{\nu_{SK}} \sim 0.05eV$, the minimal $m_{\nu_\tau}, m_{\nu_\mu}$ small mass differences might be reflected, in a spectacular way, into UHECR modulation quite above the GZK edges. The "twin" lightest masses (Fig.5-6-7) call for either gravitational ν clustering above the expected one or the presence of relativistic diffused background. Possible neutrino gray body spectra, out of thermal equilibrium, at higher energies may also arise from non standard early Universe. The UHECR acceleration is not yet solved, but their propagation from far cosmic volumes is finally allowed. The role of UHE neutrons in Z-showering, their directional flight leading to clustering in self collimated data is possibly emerging by harder spectra. Peculiar secondaries of TeVs tails may be precursor and afterglows signal correlated to past or future UHECRs pointing toward the same far sources. The IR-TeV solution may be just be a necessary corollary of the Z-Showering GZK solution (Fargion, Grossi et Lucentini 2001). The time and space directional may be a new fundamental test of present Z-Showering model. The discover of UHE neutrino at GZK energies might be testify on ground by UHE τ air-shower, born by direct 10^{19}eV UHE ν crossing small Earth crust depth, flashing from the horizontal edges to mountain,balloon and satellite detectors (Fargion 2000). The new generation UHECR data within next decade, may also offer the probe of lightest elementary particle masses, their relic densities, their spatial map distribution and energies and the most ancient and evasive shadows of earliest ν cosmic relic backgrounds.

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DISCUSSION

JIM BEALL: For photo-pion production in the AGN sources, where do the pions come from? This is a somewhat rhetorical question.

D.FARGION: In the UHE ν-ν scattering to the overcome GZK cut-off we consider two places where pions occurs:

1. Near the AGN source: the UHE photon (or nuclei) hitting BBR (2,7K) photons or local thermal photons lead to: $p + \gamma \to \triangle^+ \to \pi^+ + n$
   $p + \gamma \to \triangle^+ \to \pi^0 + p$
   or
   $p + \gamma \to N\pi + p$
   $p + \gamma \to N\pi + n$
   These UHE pions decays to UHE ν. The UHE ν^+ relic ν produce Z (UHE parent of UHECR). The Z decay into 2.7 nucleons and $\simeq 30$ pions (neutral + charged).
   The neutral pions decay into UHE γ, the charged ones decay into $\mu \to e$, and ν_e,ν_μ.

WOLFGANG KUNDT: What are your objections to a very near population of CR sources, d$\leq$ Kpc^2. (I Like to think of slingshot-acceleration of CR's by neutron-star magnetospheres).

D.FARGION: I am sorry because I was first understanding your "near objects" as Farrar-Bierman-Piran solution of AGN near (M-87 - like $\leq$ few Mpc) + B_G. They should be also UHE neutron, $\bar{n}$ ($p + \gamma \to \pi^+ + n$ by photopion), source that should point directly to M-87 (this was not observed). About "galactic" (Kpc radius) I think they should follow the galactic disk distribution with strong quadrupole modulation in UHECR (unobserved). For HALO source tiny dipole anisotropy might be hidden but present data seem not correlated with known PSR distribution.

S.COLAFRANCESCO: Which is the contribution on Ω_0 by the relic neutrinos you need ($m_\nu \simeq 0.1 \div 10eV$)in the dark halo ($R_{halo} \simeq 1 \div 2Mpc$) in order to solve the GZK problem?

D.FARGION: The amount of dark matter I consider in cosmology is linearly dependent on m_ν mass (for simplicity here I mean an unique flavour mass dominant component)

$$\Omega_\nu \simeq 10^{-2}\left(\frac{m_\nu}{eV}\right) \tag{12}$$

The amount of dark matter in galactic or local group halo has a density which may reach a density contrast:

$$\frac{\delta\varrho}{\varrho} \simeq 10^2 \div 10^3\left(\frac{m_\nu}{eV}\right)^\beta \tag{13}$$

model dependent $0 \leq \beta \leq 2$. The bounds we found up to day are fixing:
$m_\nu \gtrsim 0.1eV$(extended extragalactic halo); $2eV \lesssim m_\nu \lesssim 5eV$ (galactic halo).