U.H.E. neutrino conversion and the lepton asymmetry in the Universe

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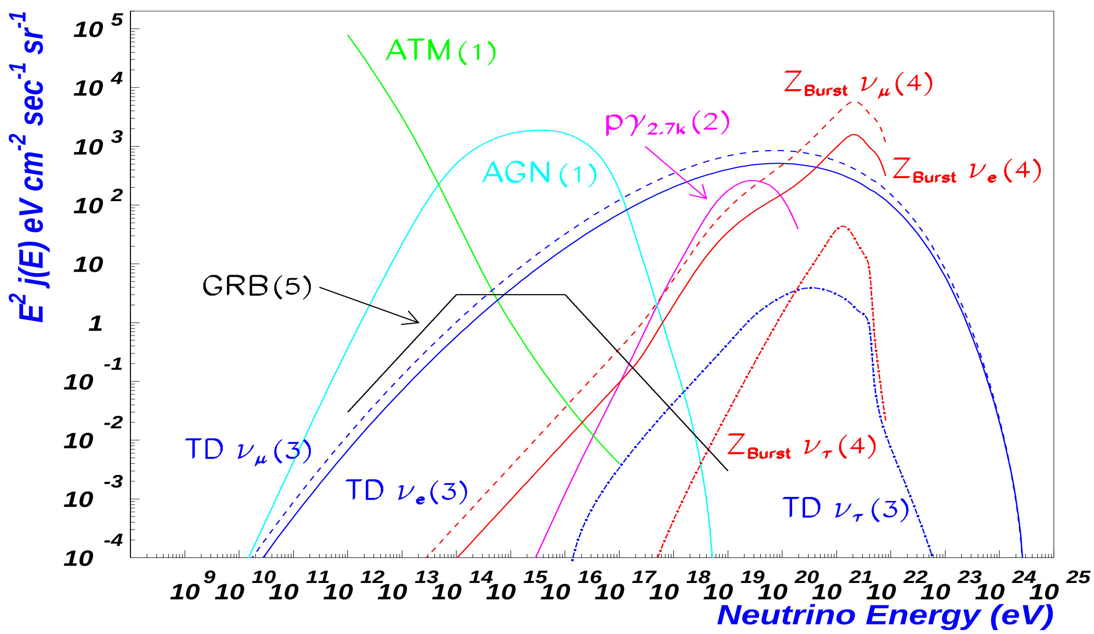
C.L. , A.Yu. Smirnov, hep−ph/0012056 , accepted by PRD

Ultra−high energy neutrinos:



are matter effects important?

how do they modify oscillations?

what information can they give?

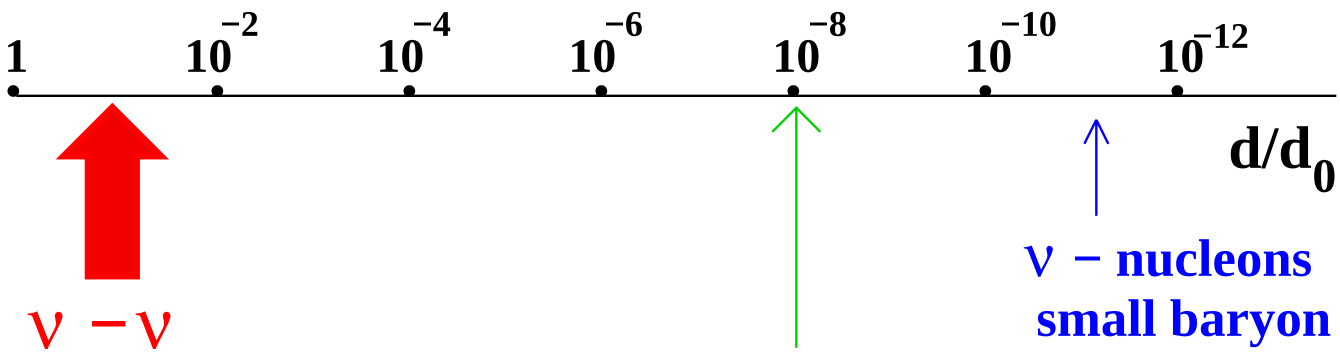
effects in the source (star, galaxy) are negligible...

but... let us consider **the universe as a medium...**

$d_0 = \frac{\pi n}{2V}$ refraction width n density, V potential

$d = \int n(t)\, dt$ width of medium

if: $d/d_0 > 1$ matter effect can be significant



$\nu - \nu$
with large CP asymmetry and
cosmological source

$\nu -$ photon:
small interaction
(G_F^2)

$\nu -$ nucleons :
small baryon asymmetry
$(\eta_B = 10^{-10})$

$$d/d_0 = 1.6\ 10^{-2} F \eta \ \left((1+z)^{3/2} - 1 \right)$$

$F \approx 1$

η CP asymmetry z redshift

some info about CP asymmetry of the relic neutrino background

$$\eta = \frac{n(\nu) - n(\bar{\nu})}{n(\gamma)}$$

Bounds:

1. BBN (nucleosynthesis , T= 1 MeV) :

$$|\eta_{\mu,\tau}| \le 10 \qquad -0.01 \le \eta_e \le 0.3$$

2. CMBR (microwave background, T =1 eV)**:**
(fits)

$$|\eta_{e,\mu,\tau}| \le 2.2$$

in presence of ν masses and mixings
the asymmetries evolve with time...

how to proceed :

suppose η produced
at T> T(BBN)
take mixing θ and Δm^2

Oscillations

collisions

evolution to present epoch

bounds from BBN and CMBR

expansion of the universe

today (z < 50):

present η , flavour composition

ν are in mass eigenstates (decoherence)

U.H.E. ν : active−active oscillations

The refraction potential
is diagonal in the mass basis .

↓ (check !)

matter ''corrects''the masses,
no modification of mixing !

only the oscillation phase is modified.

conversion probability:

$$P(t, t_i) = \sin^2 2\theta \sin^2\left(\frac{\Phi_\nu + \Phi_m}{2}\right)$$

i= initial
0=present

$$\Phi_\nu = \frac{3}{10}\,\frac{\Delta m^2 t_0}{E_0}\left(x^{5/3} - x_i^{5/3}\right) \qquad x = t/t_0$$

$$\Phi_m = V_0\, t_0 \left(\frac{1}{x_i} - \frac{1}{x}\right)$$

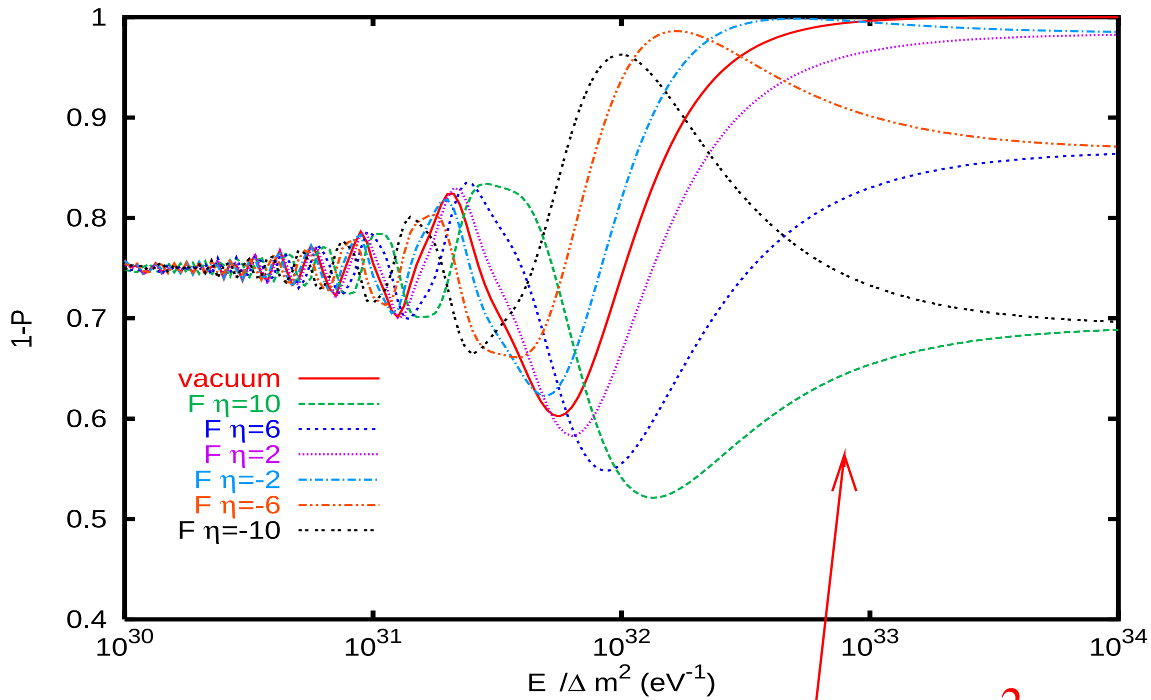
accumulated at production

dominates at high E_0

$$V_0 = F(\theta)\,\eta\,\sqrt{2}\,G_F\, n_\gamma^0$$

η = Max{η_e, η_μ , η_τ} at BBN

Survival probability:



$\sin^2 2\theta = 0.5$

$z = 3$

Φ_m dominance

($\Phi_v \simeq 0$)

Significant effect requires:

distant source: large z

large η

large mixing

$\Delta m^2 \lesssim 10^{-10}$ eV ^{2}

active – sterile conversion:

the matrix of potentials is diagonal
in the flavour basis

→ both the phase and
the mixing are modified.

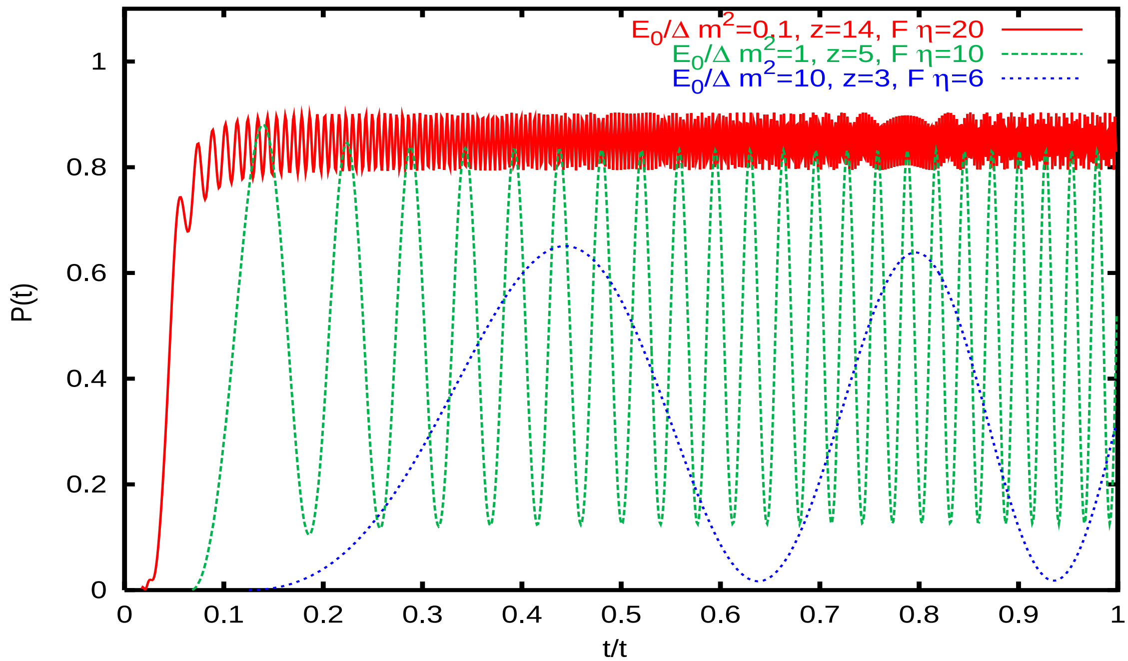
$$V = F \eta \, G_F \sqrt{2} \, n_\gamma$$

for $z < 5-6$ and $\eta < 10$ we find that
the dynamics of propagation consists in:

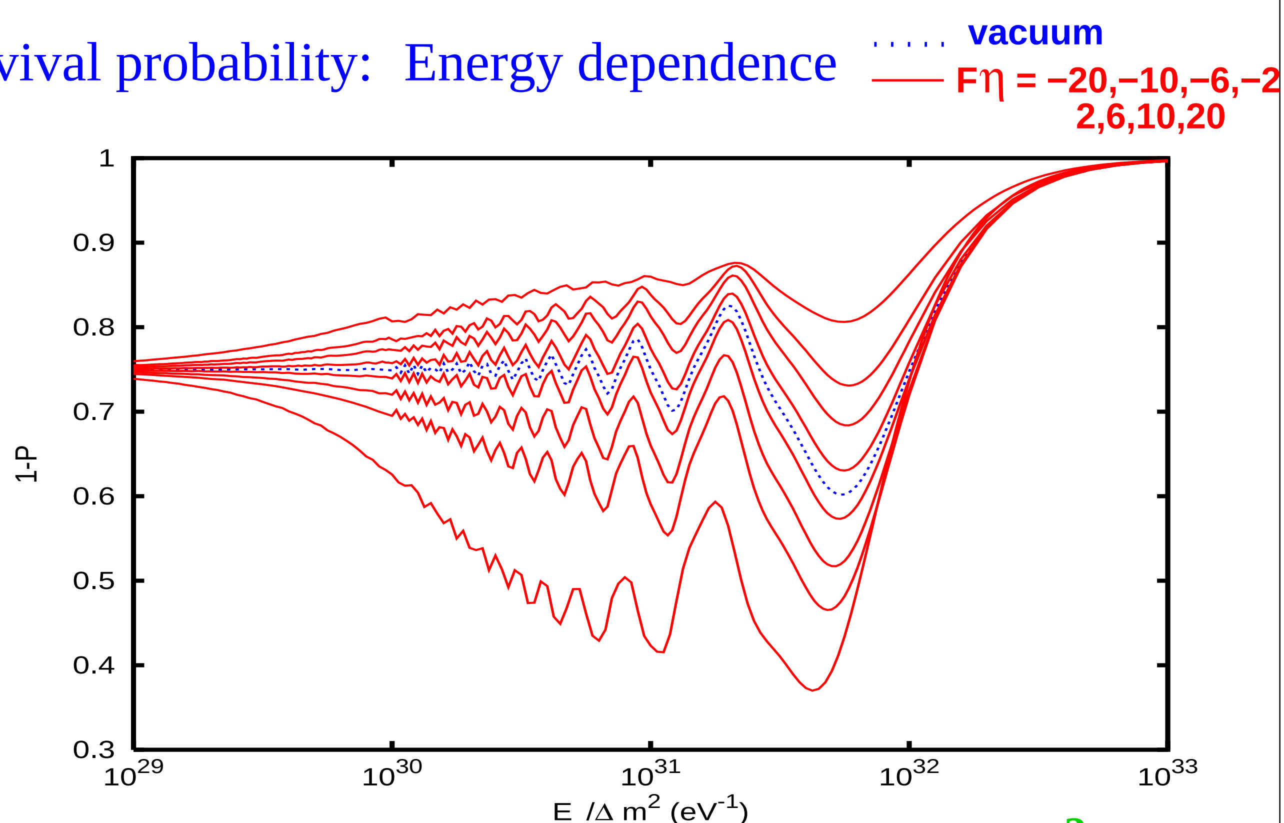
- non-adiabatic level crossing
  (redshift of energy;
  expansion of the universe)

- enhancement of mixing at the
  the production epoch

Time evolution :



survival probability: Energy dependence



significant effect requires :

- large z
- large η
- $0.3 < \sin^2 2\theta < 0.95$, $\Delta m^2 \leq 10^{-9}$

$\sin^2 2\theta = 0.5$

$z = 3$

observing point sources is difficult... but there is chance to see diffuse fluxes from all the sources

Integrated conversion probability :

$$\frac{F^{\alpha}(E_0)}{F_0^{\alpha}(E_0)} = 1 - \overline{P}_{\alpha}(E_0)$$

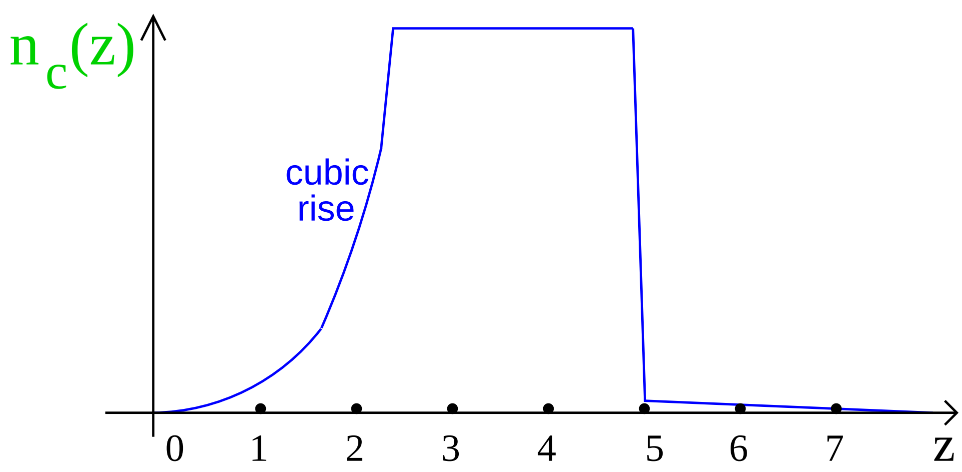
$$\overline{P}_{\alpha}(E_0) \propto \int \underbrace{f\,(E_0(1+z))}_{\text{produced flux}}\, \underbrace{n_c(z)}_{\text{comoving density of sources}}\,(1+z)^{-3/2}\, P_{\alpha}(E_0\,, z)\, dz$$

produced flux

comoving density of sources

e.g. for GRB :
(gamma ray bursters)

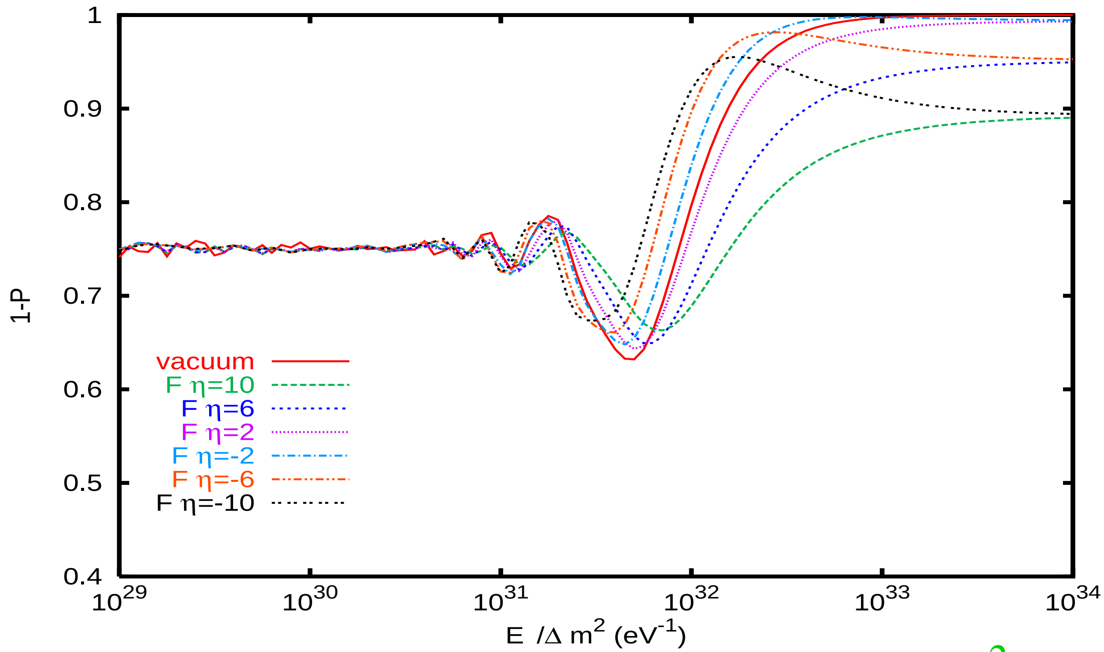
$$f\,(E) \propto E^{-2}$$



> **the contribution of distant sources (large z) is suppressed**

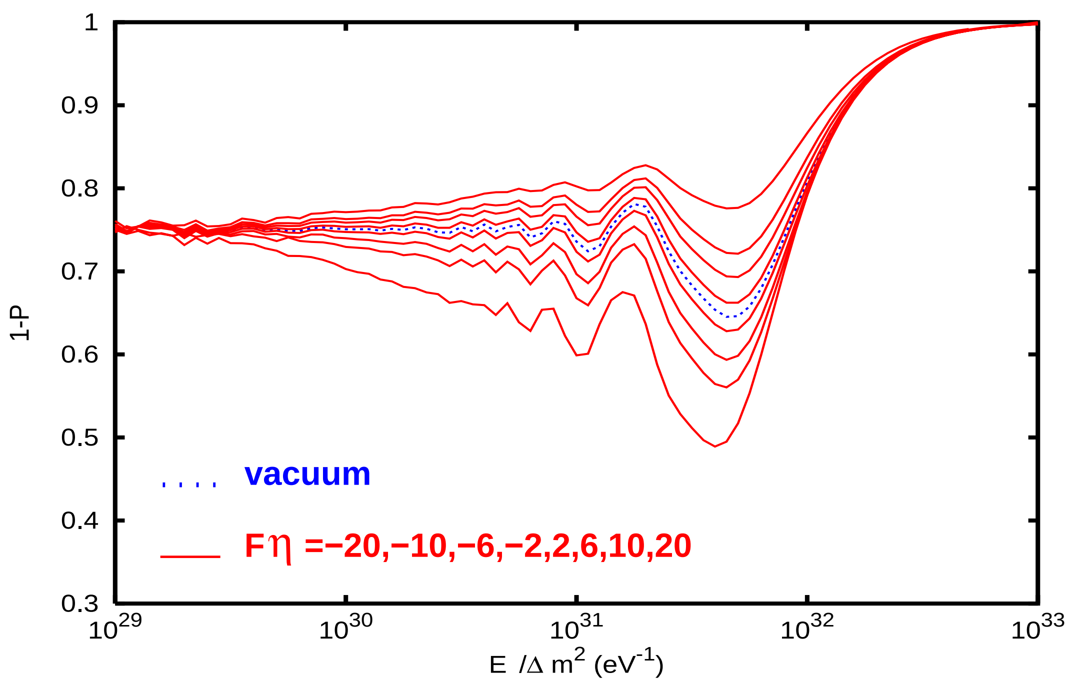
diffuse flux from GRB: survival probability

active − active:



$\sin^2 2\theta = 0.5$

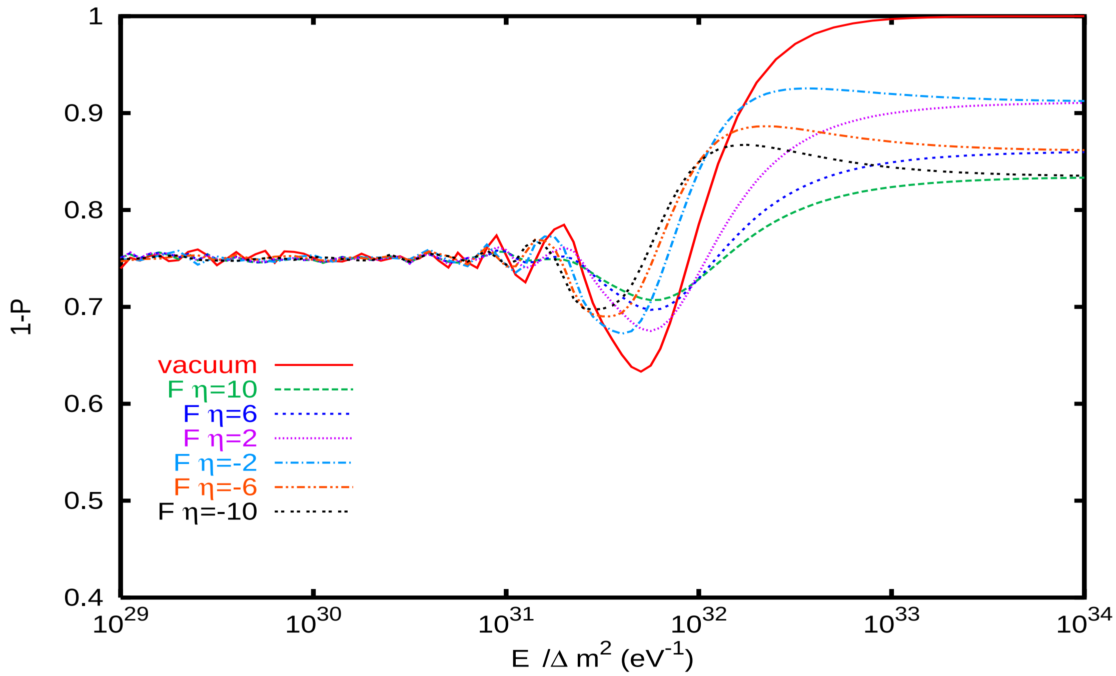
active − sterile:



for heavy particles decay: $X \longrightarrow \nu + \textbf{any}$

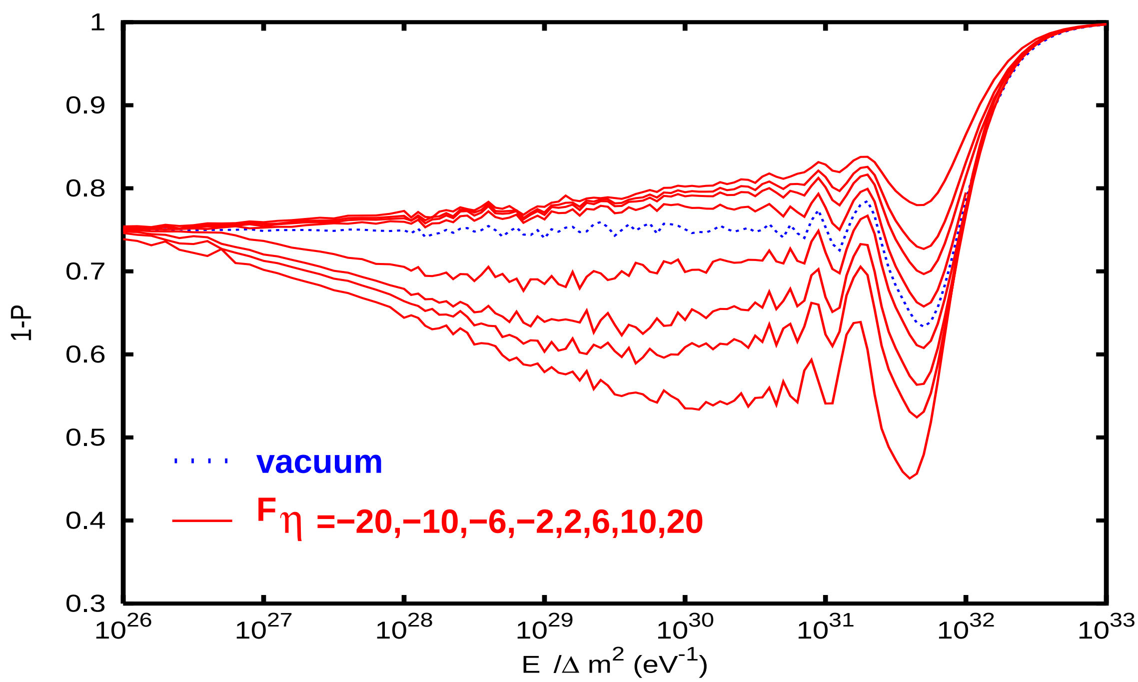
survival probability:

active − active :



$\sin^2 2\theta = 0.5$

active−sterile :



What can be observed ?

take e.g. the ratio of numbers of events:

$$R = \frac{N(e+\bar{e})}{N(\mu+\bar{\mu}) + N(\tau+\bar{\tau})}$$

No mixing: **R given by the original flavour composition.**
$(\theta = 0)$

e.g. $R_0 = \frac{0+1}{1+1+0+0} = \frac{1}{2}$

with vacuum oscillations:

$R = R_\nu(R_0, \theta, \cancel{E_0})$ **for** $E_0/\Delta m^2 < 10^{31}\ eV^{-1}$
(averaged oscillations)

$R \approx R_0$ **for** $E_0/\Delta m^2 > 5\ 10^{32}\ eV^{-1}$

with effects of the neutrino background:

active–active: different asymptotic

$R = R_\nu(R_0, \theta)$ for $E_0/\Delta m^2 < 10^{31}$ eV^{-1}

$R \neq R_0$ for $E_0/\Delta m^2 > 5\ 10^{32}$ eV^{-1}

active–sterile: different energy dependence

$R = R(R_0, \theta, E_0)$ for $10^{30} < E_0/\Delta m^2 < 10^{32}$ eV^{-1}

$R \approx R_0$ for $E_0/\Delta m^2 > 5\ 10^{32}$ eV^{-1}

$(R - R_\nu)/R_\nu \leq 10\ \%$

accidental cancellations can occur...
($\theta_{atm} = \pi/4$)

Conclusions :

If large CP asymmetry $(\eta > 1)$ exists

in the relic neutrino background

the U.H.E. neutrinos ‘‘feel’’ it.

the modification of vacuum oscillations
is different for active−active and active−sterile channels

for both of them the effect requires:

$\eta \geq 1$ $\quad$ $z > 1$

$0.3 < \sin^2 2\theta < 0.95$ $\quad$ $\Delta m^2 < 10^{-9}$ eV^2

ratios of numbers of events can deviate
from what expected from vacuum oscillations

by $\sim 10 - 15$ %

more work needed...
waiting for large scale detectors . . .