A non-standard neutrino interaction

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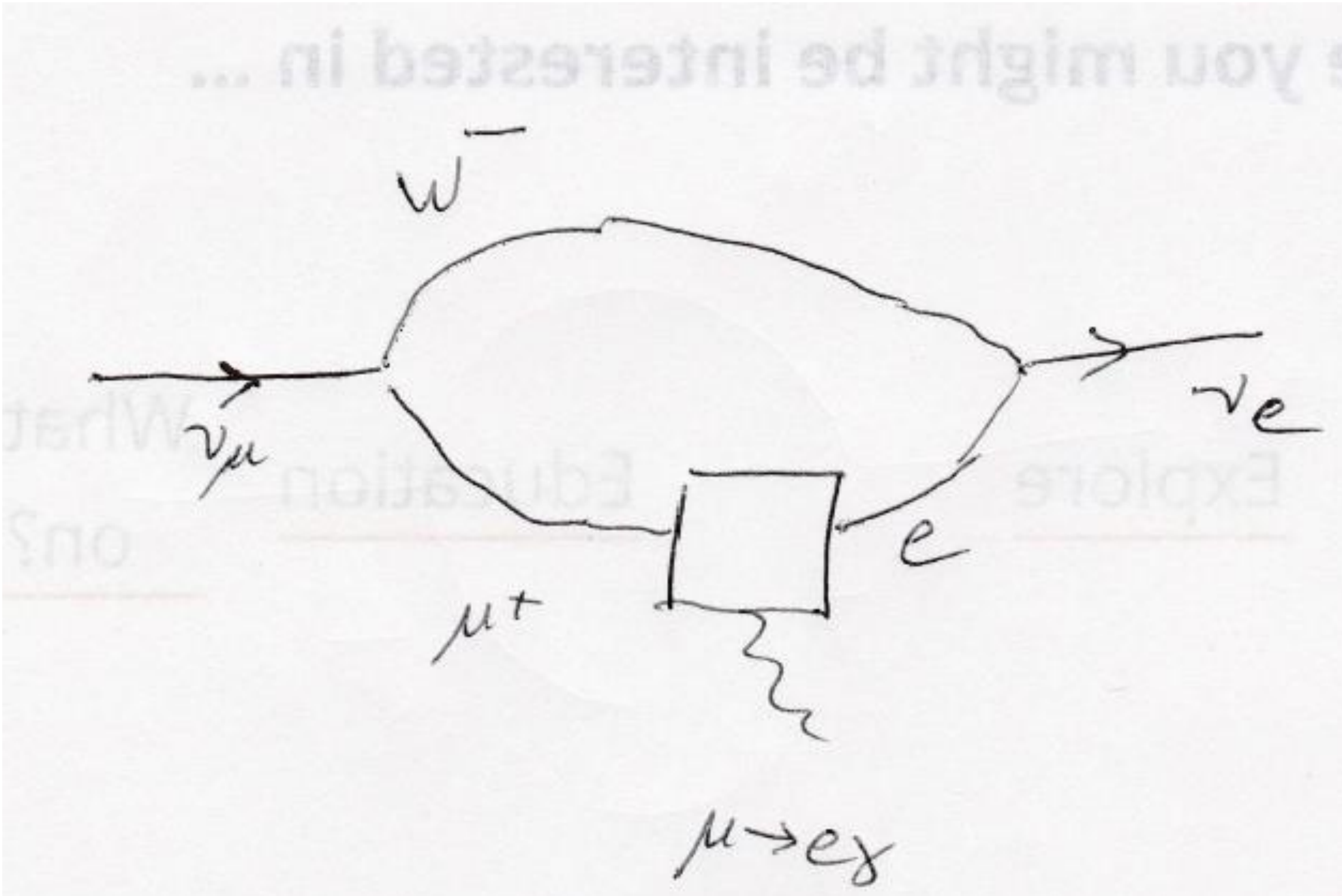
Meeting on exploring exotic physics with current neutrino detectors 14 Dec 2015.

A scenario is described which may allow the decay ν→ $\nu' + \gamma$ where ν is a heavy mass eigenstate and ν' is a lighter one.

Theory of Ishikawa and Tobita.

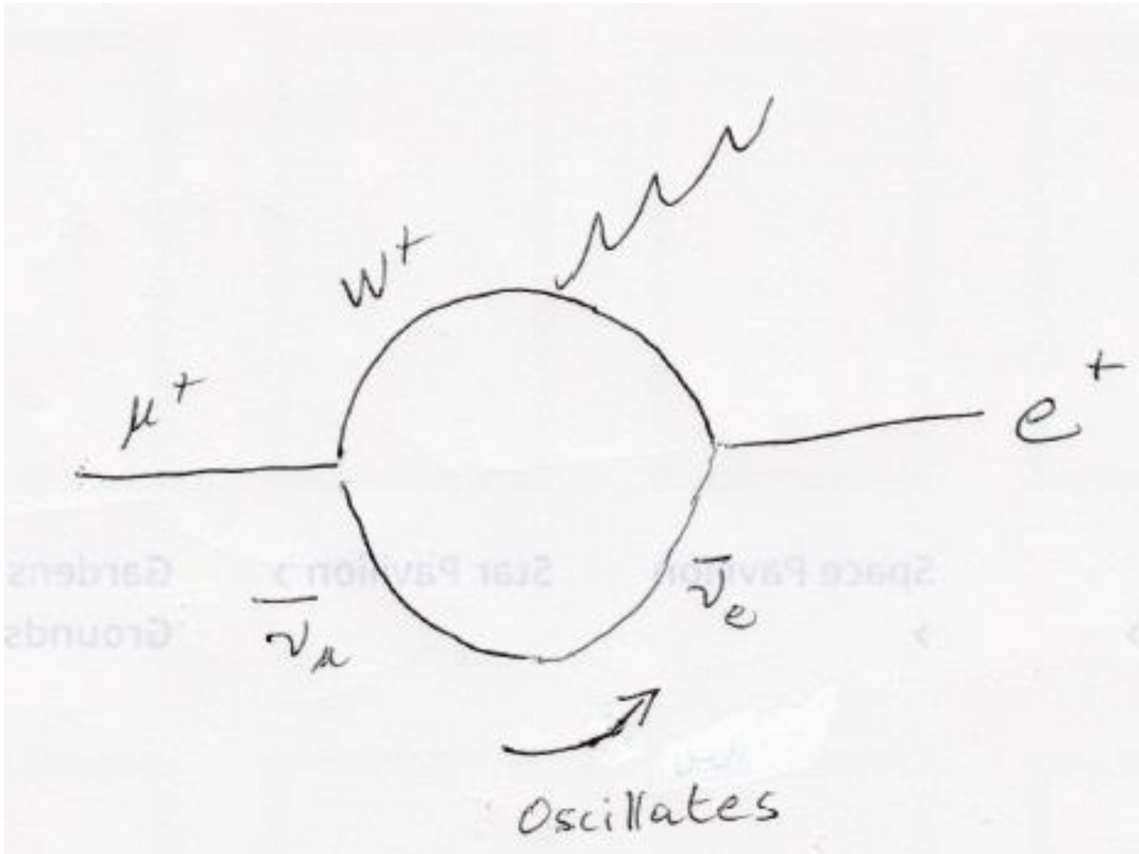
If this theory is correct it could make neutrino detection much easier and explain a number of phenomena.

Standard model computation for $\nu \rightarrow \nu'\gamma$ gives a very low rate.



NB μ->eγ in virtual loop so decay rate even smaller.

Decay $\mu \rightarrow e + \gamma$ - SM gives a small branching ratio $\sim 10^{-54}$
(Bernstein and Cooper arxiv:1307.5787)



Beyond SM processes e.g. supersymmetric loops could give a BR ~ $10^{-10} – 10^{-14}$

There is an ongoing experimental program to look for this decay (MEG collaboration),

Ishikawa and Tobita idea

There are approximations in the standard model calculations. When computing Feynman graphs the assumptions are made of plane wave functions for the particles and an infinite source size and no overlap between initial and final states.

However, when one includes non-plane wave functions from a finite source size and allows overlap between the initial and final wave functions the resulting transition probability P=$\Gamma T + \varepsilon$ (*T*=time, P<< 1) where *Γ* = transition rate computed from the Feynman graph and *ε* is a correction arising from the approximations.

If the waves are plane and there is no overlap of the waves ε~0.

In practice for transitions involving massive particles ε is small.

However, for very low mass objects e.g. neutrinos ε could be significant

Especially when *Γ* is very small (as in $\nu \rightarrow \nu' + \gamma$).

Ishikawa and Tobita (arxiv:1503.07285) show that in their theory there is a quantised electroweak Hall effect which gives $\varepsilon = P^{(d)}(\gamma)$ where

$$P^{(d)}(\gamma) \approx P^{(d)}_{\rm asym}(\gamma)\frac{T}{T_0},\ T_0 = \frac{1}{\omega_\gamma};\ \omega_\gamma T < 1, \tag{9}$$

$$P^{(d)}_{\rm asym}(\gamma) = \eta\frac{\alpha}{5\pi}\left(\frac{G_F}{(c\hbar)^3}E^2_{\nu_1}\right)^2\frac{\delta m^2_\nu}{m^2_{\gamma,\rm eff}}\left(\frac{\nu^{(4)}}{2\pi}\right)^2\sigma_\gamma;\ \omega_\gamma T \geq 1, \tag{10}$$

$$\eta = \cos^2\Theta_{B,\bar{p}_{\nu_1}}\cos^2\theta_{12},$$

Here $\nu^{(4)} = {}^{hn_e}/_{eB}$ is a filling factor for the quantised cyclotron orbits (the quantum Hall effect) σ_γ is a term representing the source size.

NB the effect is strongly energy dependent ($\propto E^3$).

Plasma physics

A neutral plasma consists of equal numbers of positive ions and electrons.

Displace electrons from positive ions sets up an electric field – release gives an oscillation at a characteristic frequency – the plasma frequency

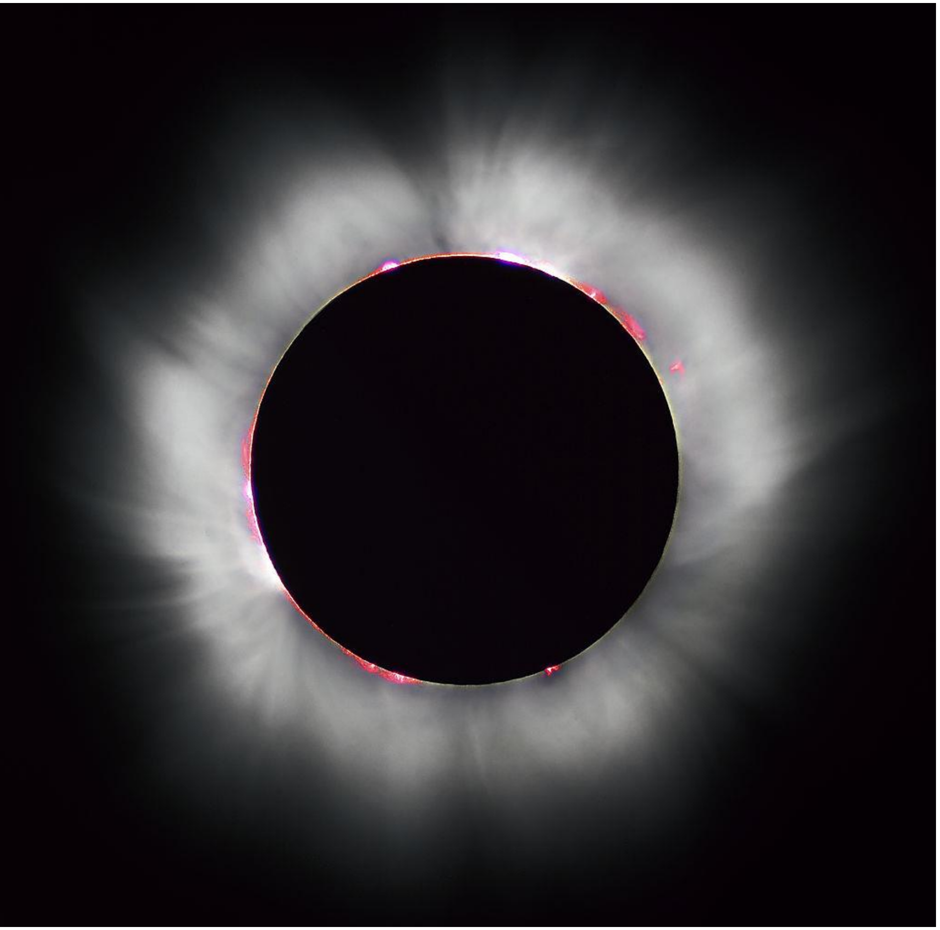
$$\omega_P = \sqrt{\frac{n_e e^2}{m\varepsilon_0}} \text{ (SI units)} = \sqrt{\frac{4\pi n_e e^2}{m}} \text{ (cgs units)}$$

Media with such resonant frequencies are dispersive – so a wave of frequency ω has quantum of energy $\hbar\omega$ and momentum $\hbar k = \frac{2\pi\hbar}{\lambda}\sqrt{(1 - \frac{\omega_P^2}{\omega^2})}$

Photon picks up an effective mass $m_{eff}c^2 = \sqrt{(\hbar\omega)^2 - (\hbar k)^2} = \hbar\omega_P$

NB $m_{eff} < \delta m_\nu$ for neutrinos for plasma densities < $5\ 10^{15}$ per cm^3

The process $\nu \rightarrow \nu' + \gamma$ only occurs in plasmas of low density when $m_{eff} < \delta m_\nu$



Solar corona is at a temperature of 10^6K while solar surface is at 6000K – WHY?

Ishikawa and Tobita (IT) propose that it is the Electroweak Hall Effect?

For the solar corona IT compute $\varepsilon \sim 10^{-3}$ i.e. 1/1000 of the solar neutrinos convert and heat up the corona.

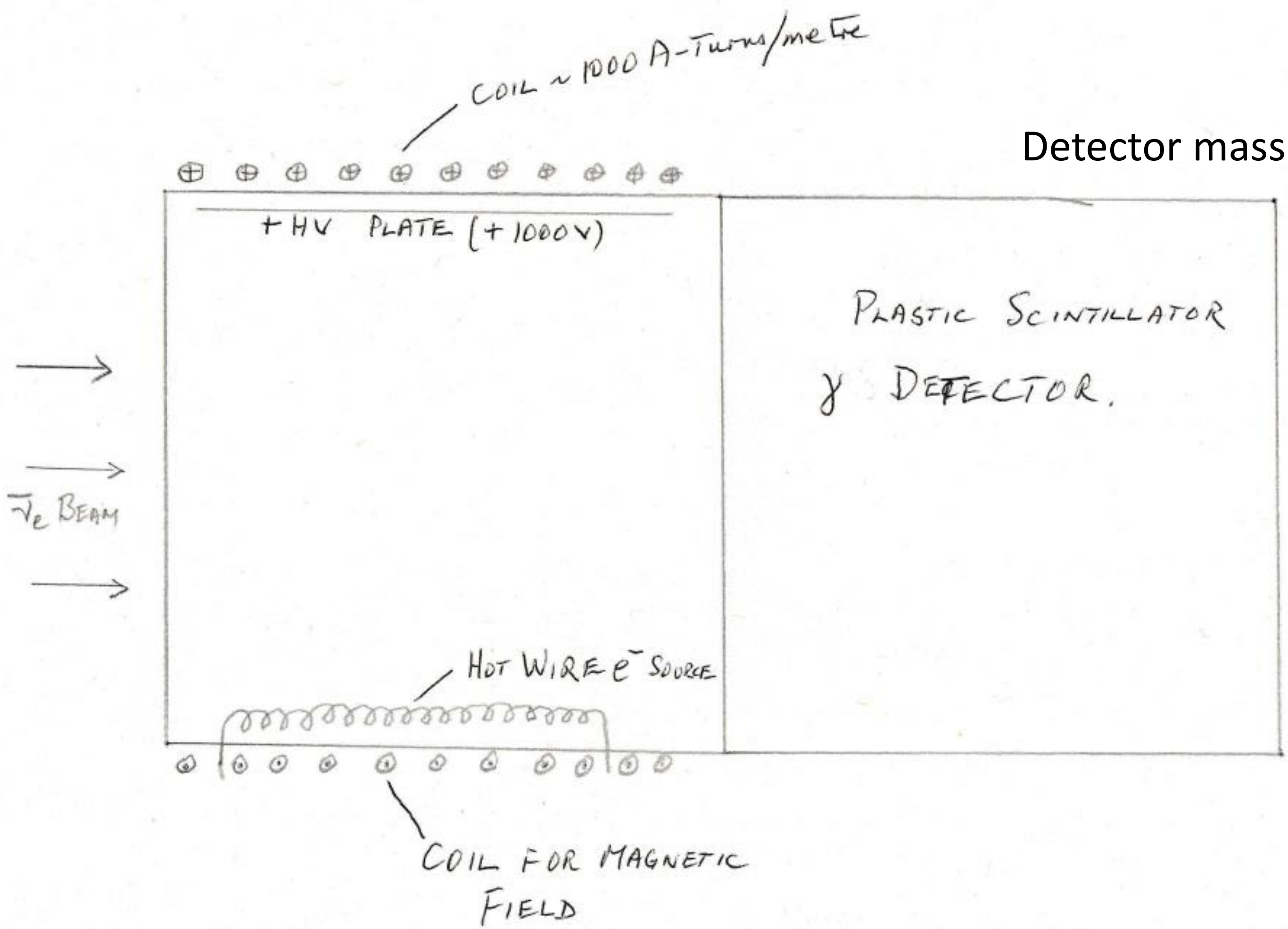
Solves the long standing problem in solar physics of why solar corona temperature is so high.

To confirm this picture we need an experiment.

Test by doing an experiment – put a box of plasma in a neutrino beam.

Box shown below is 1 m^3 in volume with 1/3 ton plastic scintillator to detect γs.
Ishikawa and Tobita estimate $\varepsilon \sim 10^{-14}$ to 10^{-13} at $E_\nu = 10$MeV and assume E^3dependence.

Detector mass ~1/3 ton



Look at 3 scenarios for the experiment

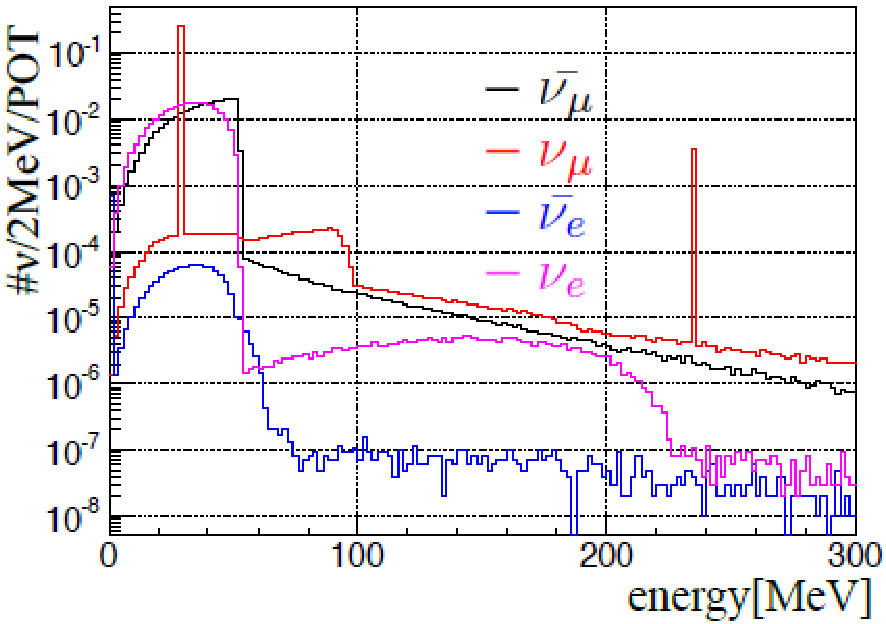
1. MLF at JPARC (3 GeV proton beam hitting mercury target – gives neutrinos from stopped pions and muons –
   i.e. mixed flavours of mainly electron neutrinos and muon anti-neutrinos from μ+ decay and muon neutrinos from pion decay (energies 0-50 MeV).

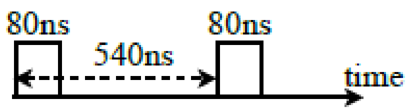
2. Reactors – electron anti-neutrinos energy ~2 MeV

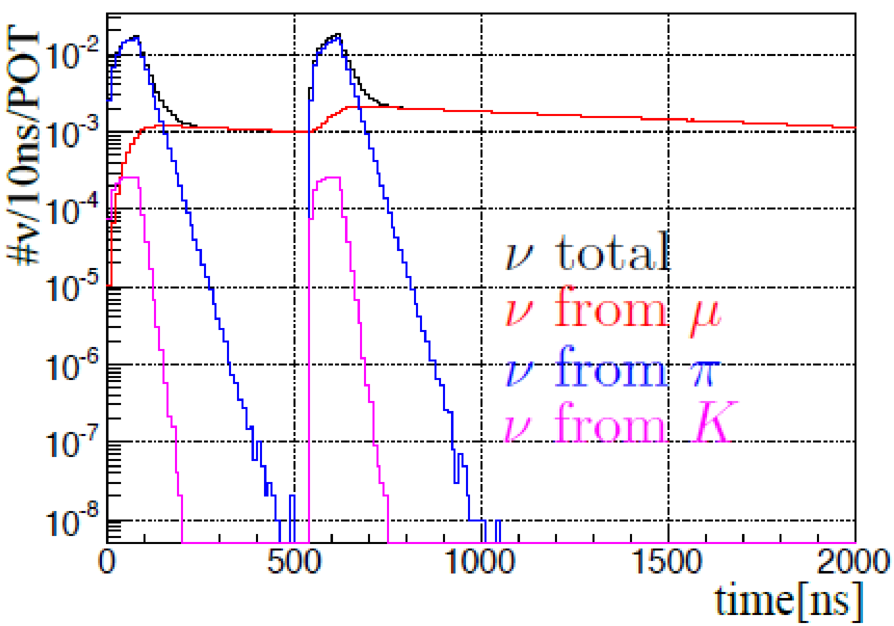
3. T2K muon neutrinos and anti-neutrinos.

NB in solar corona electron neutrinos of energy up to 20 MeV (mainly ^{8}B flux at higher energies) – most closely matched to MLF neutrinos.

Count rates extrapolated from Ishikawa and Tobita estimate of $\varepsilon \sim 10^{-14}$ to 10^{-13} at 10 MeV inside our box of plasma
i.e. assume $\varepsilon \sim 10^{-17} - 10^{-16} E_{\nu}^{3}$ with energy in MeV







MLF neutrinos – from 3 GeV protons in mercury target producing floods of low energy pions which stop and positives decay.

Recall decays $\pi^+ \rightarrow \mu^+ + \nu_\mu$(lifetime 26 nsec)
and $\mu^+ \rightarrow e^+ \overline{\nu_\mu} \nu_e$ (lifetime 2.2 μsec)

Counting rates in the box experiment are of order 10^{-3} to 10^{-2} per spill

(i.e. 90-900 per hour in a 1/3 ton detector).

Contrast this with the experiment E56 expected count rate of 10^{-4} per spill

(i.e. 9 per hour in a 50 ton detector).

If Ishikawa and Tobita are right we have a much more efficient way of detecting neutrinos

Box in the T2K Beam

OFF AXIS

Assume 7 10^{12} neutrinos at a mean energy of 600 MeV per 10^{21} POT.

Count rate in the simple box experiment is $\sim 2\ 10^4$ to 2 10^5 photons per 10^{21} POT

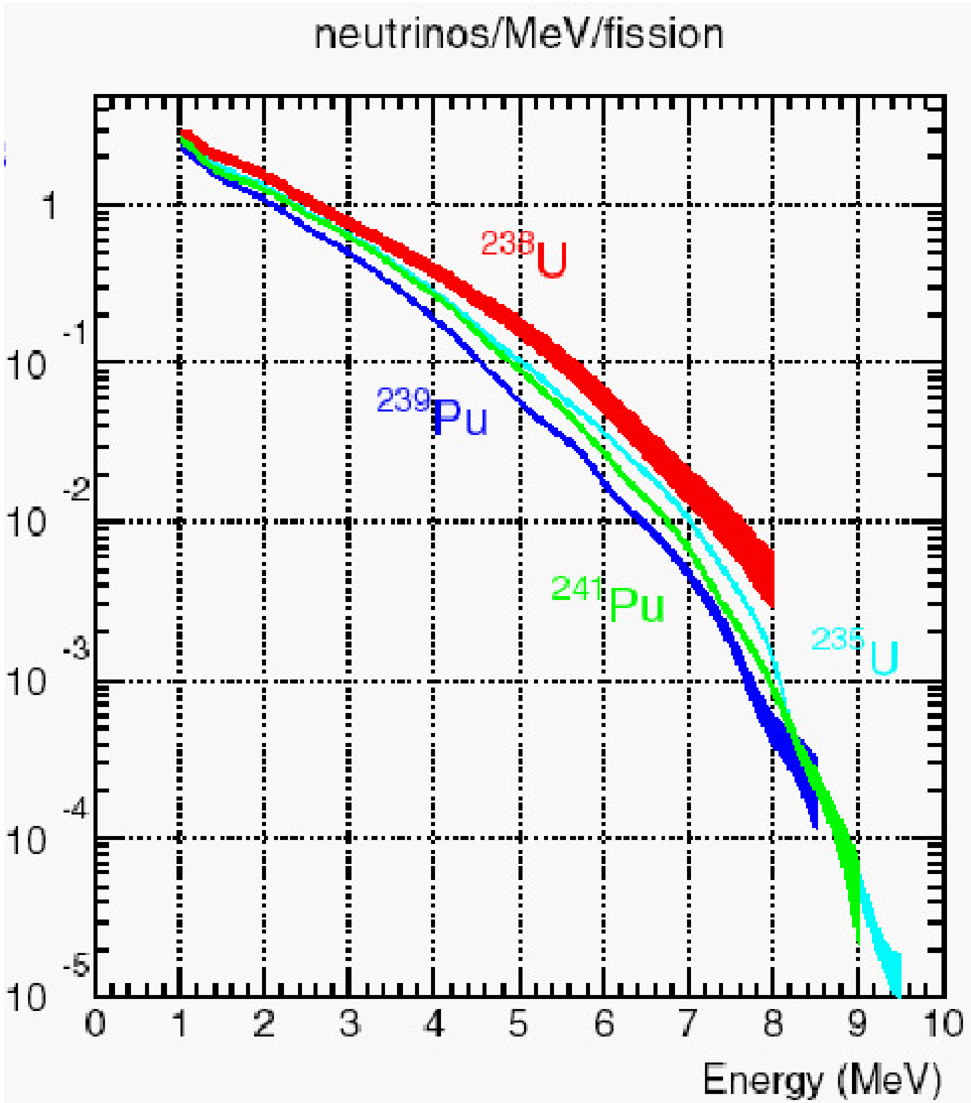
ON AXIS

Assume 21 10^{12} neutrinos at mean energy of 1300 MeV

Count rate 5 10^5 to 5 10^6 photons

i.e. healthy count rates.

Reactor $\bar{\nu}_e$ source.



Low energy electron antineutrinos.

Estimated count rate integrating over spectrum of order 3 -30 counts per second from a 1 GW reactor.

NB low energy photons close to noise.

Spectrum from J.Cao arxiv:1101.2266

Compare the sources.

I favour the MLF – high count rate of photons of energy 5-30 MeV.
It is a source of ν_e as in corona (as well as $\nu_\mu$from π^+ decay and $\overline{\nu_\mu}$).
So this is closest to the ^{8}B ν_e spectrum proposed to cause heating of solar corona.
The different flavours can be selected by timing relative to the spill.

T2K neutrinos – healthy count rates but high energy muon neutrinos and antineutrinos – different from ν_e in solar corona and at much higher energy

Reactors – low count rates of a few per second of low energy photons where noise rates are likely to be of order hundreds of Hz (also they are $\overline{\nu_e}$)

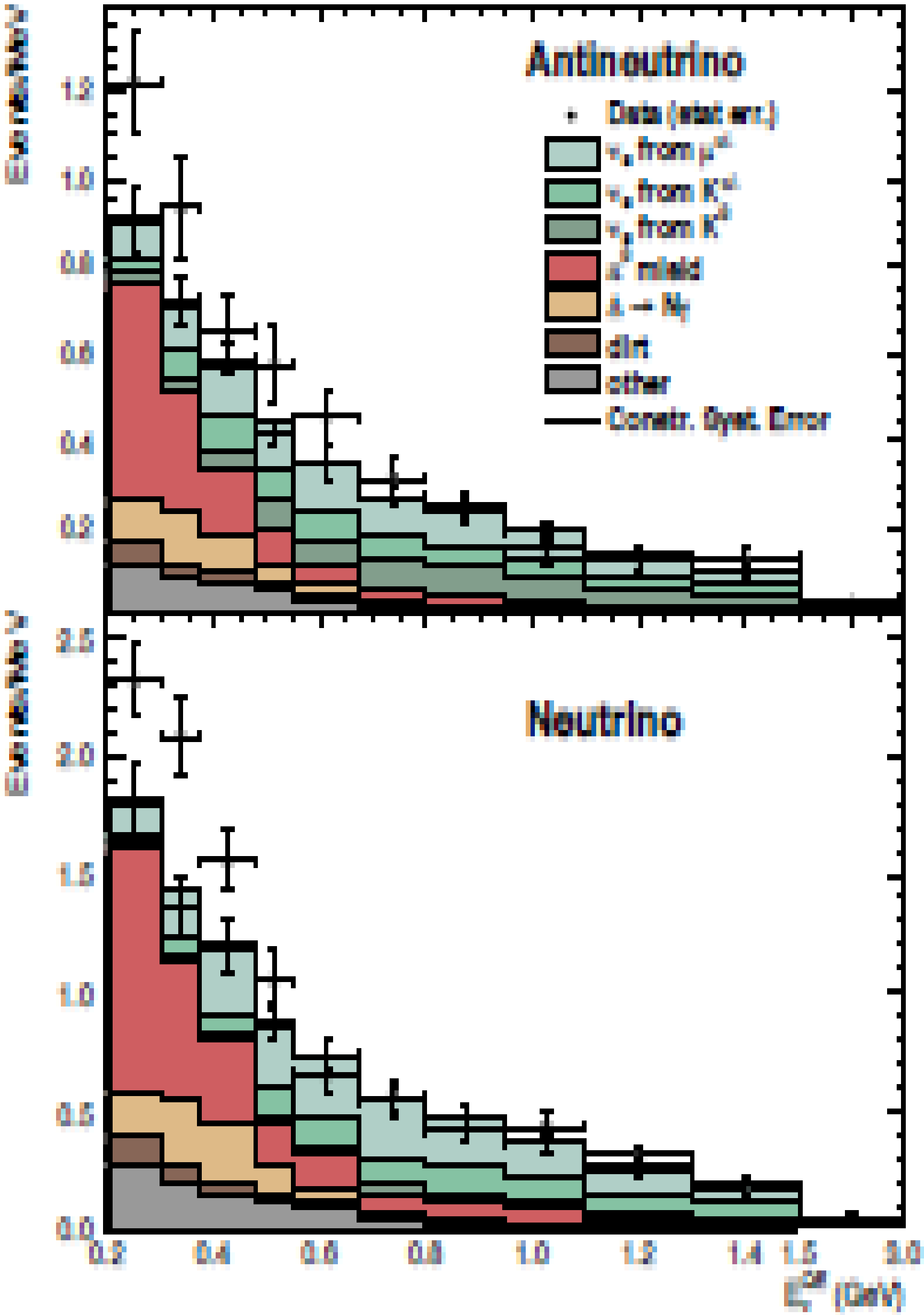
Conclusions

Ishikawa and Tobita propose an interesting idea which would allow a dilute plasma to stimulate the decay $\nu \rightarrow \nu'\gamma$ (small rate in SM). This could explain cosmological phenomena – such as heating of solar corona (and SN1987a spectrum).

Is the effect the source of sterile neutrinos?

To prove the idea needs an experiment.

Estimates show that if the idea is correct it will lead to much simpler neutrino detectors with much lower mass and higher count rates than in the very large detectors of today.



Sterile neutrinos because -

Miniboone see ν_e excess
LSND see one also
Karmen sees nothing
T2K sees nothing

Could this confusing situation be caused by the IT effect with different small amounts of plasma volume in each expt?

Different geometrical effects as well as plasma