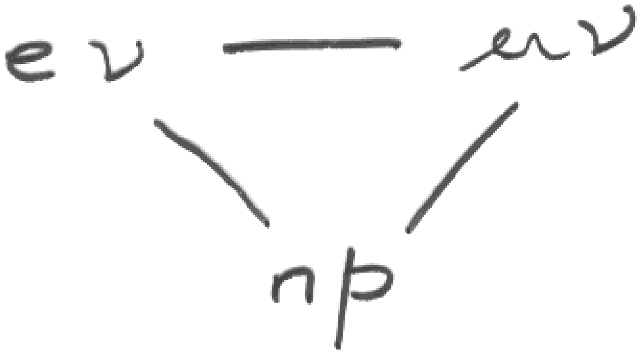
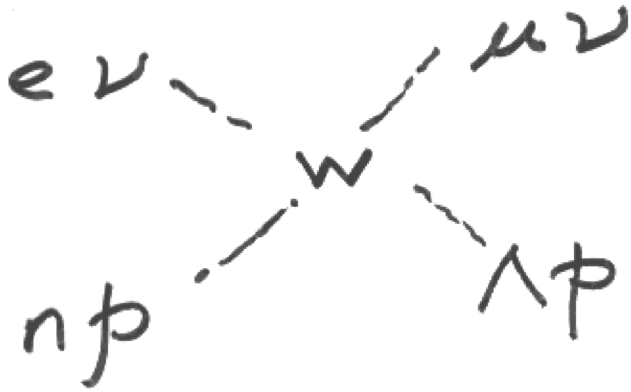
# Hadron-lepton symmetry

1949 Puppi triangle




1959 Marshak et al



$$\begin{pmatrix} u \\ d' \end{pmatrix} \quad \begin{pmatrix} c \\ s' \end{pmatrix}$$

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \quad \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}$$

$$d' = d \cos\theta_c + s \sin\theta_c$$

$$s' = -d \sin\theta_c + s \cos\theta_c$$

Charm – Glashow – Bjorken 1964

GIM 1970

SLAC 1974

<u>BUT</u>

1975 $\tau$ PERL

# QUARK - LEPTON Symmetry

QUARKS $\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$

LEPTONS $\begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

(1) THREE GENERATIONS
(2) MASS HIERARCHY
(3) SAME WEAK INTERACTIONS

EXACT SYMMETRY BROKEN AT SOME SCALE $\Rightarrow$
EXISTENCE of $\nu_R$

TO EXPLAIN SMALL $\nu$ MASSES ASSUME
SYMMETRY BREAKING $\rightarrow$ LARGE $M_R$

SEESAW MECHANISM

$$\left(\begin{array}{c|c} 0 & m_D \\ \hline m_D & M_R \end{array}\right)$$

$$m_\nu \sim \frac{m_D^2}{M_R}$$

where $m_D \sim$ normal quark mass

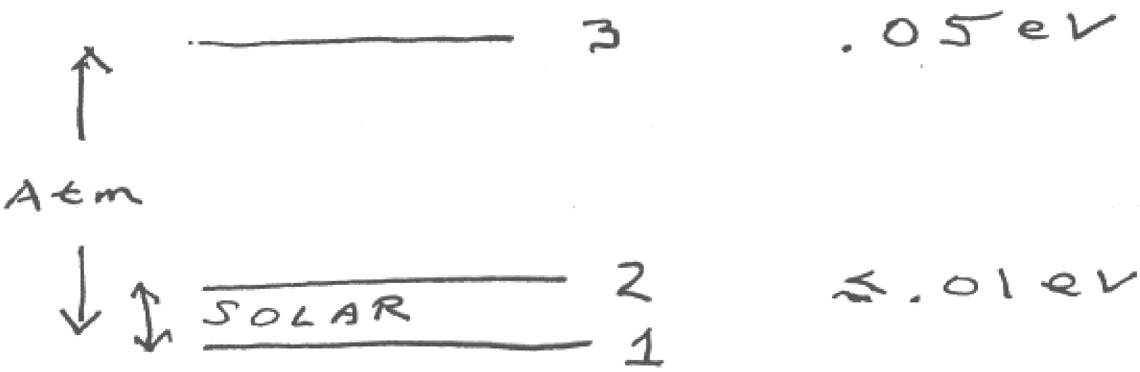
$$\nu_3 = (\nu_\mu + \nu_\tau)/\sqrt{2} \qquad + \; s_{13}\,\nu_e$$

$$\nu_2 = c_{12}\,(\nu_\mu - \nu_\tau)/\sqrt{2} \qquad + \; s_{12}\,\nu_e$$

$$- \, s_{13}^{*}\, s_{12}\,(\nu_\mu + \nu_\tau)/\sqrt{2}$$

$$\nu_1 = -s_{12}\,(\nu_\mu - \nu_\tau)/\sqrt{2} \qquad + \; c_{12}\,\nu_e$$

$$- \, s_{13}^{*}\, c_{12}\,(\nu_\mu + \nu_\tau)/\sqrt{2}$$




CP VIOLATION

$$s_{13} = |s_{13}|\, e^{-i\delta}$$

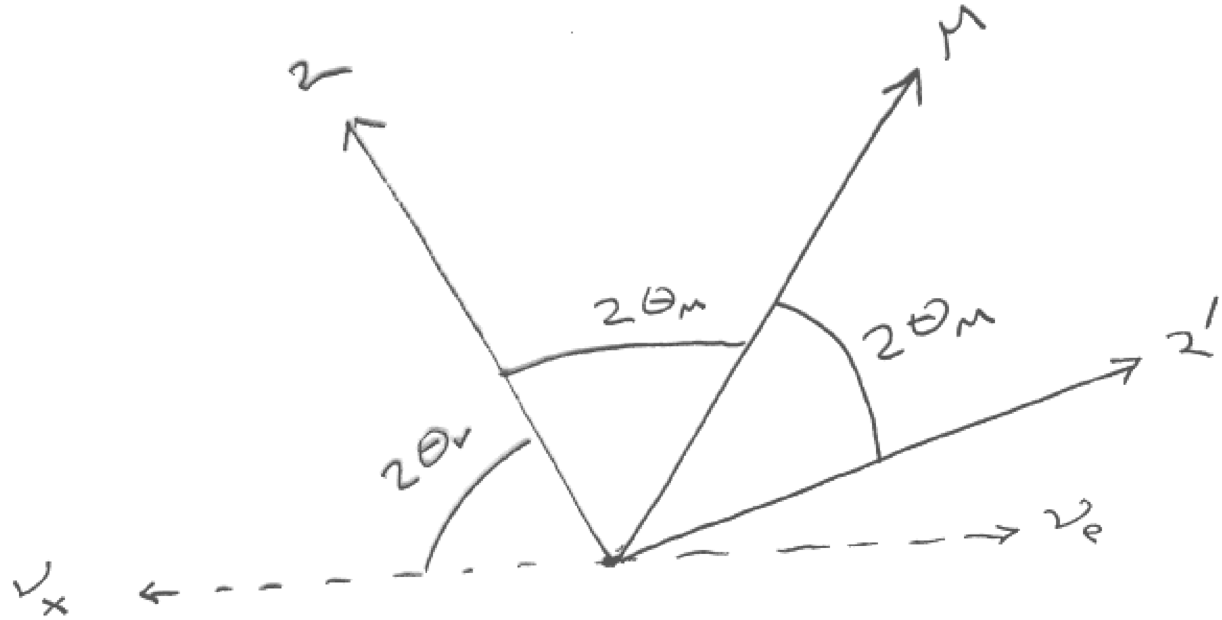
POSSIBLE

# MATTER EFFECTS

1. DAY-NIGHT EFFECT ON SOLAR NEUTRINOS
2. ENHANCEMENT OF $\nu_\mu \to \nu_e$ FOR $\nu_\mu$ TRAVERSING EARTH
3. MIMICS CP VIOLATION $\nu_\mu \to \nu_e$ COMARED TO $\overline{\nu_\mu} \to \overline{\nu_e}$

Figure 1

SOLAR ν Day-Night Effect



$\nu_\mu \to \nu_e$ Transition Probability Thru Earth at Angle $\theta$

$\sin^2 2\theta_{e3} = .025$

$\Delta m^2 = 10^{-3}$

— $\cos\theta = -.98$

.... $\cos\theta = -.85$

Tr. Prob $\approx \frac{1}{2} P_2$

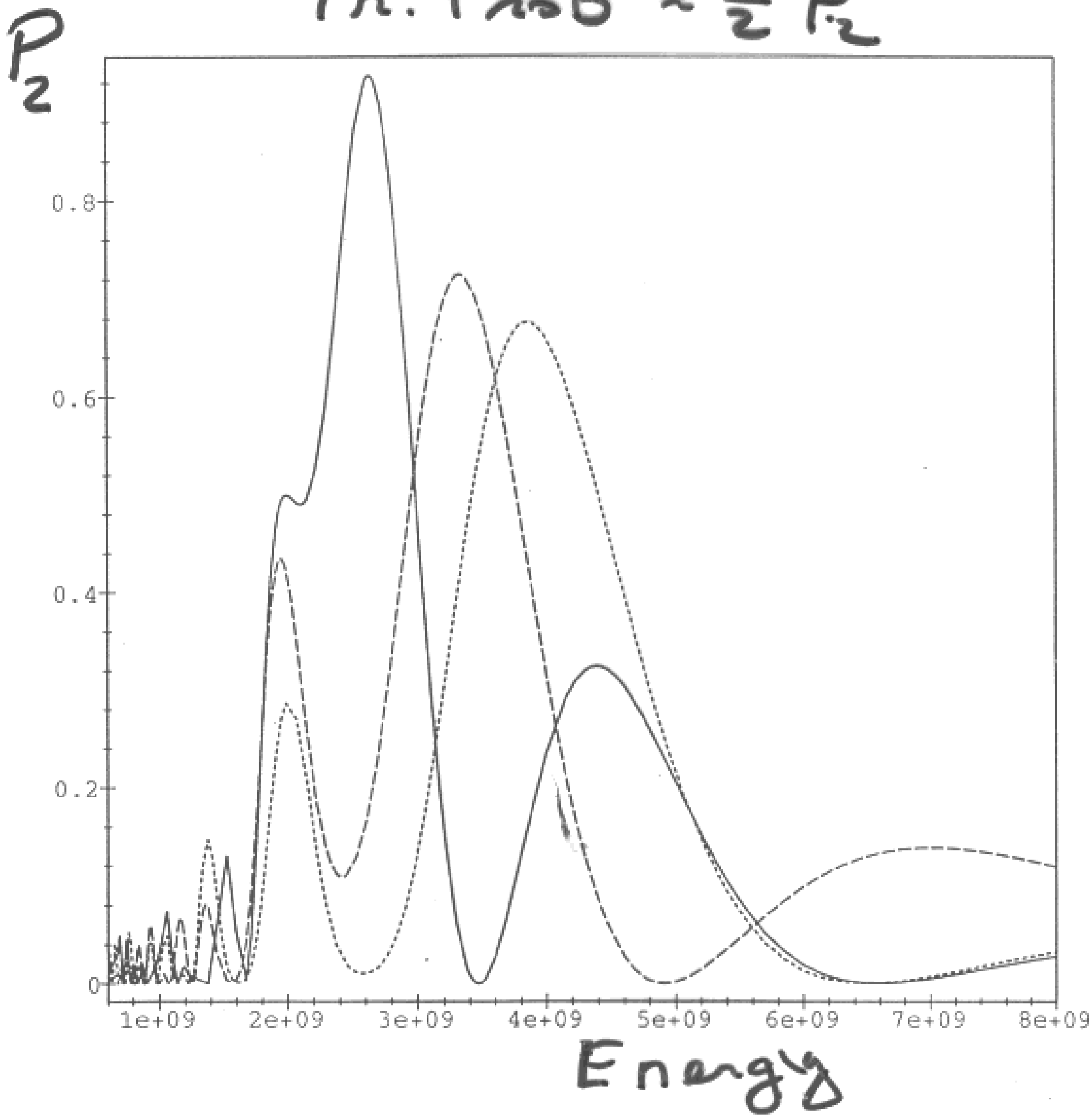



Figure 1a

Possible $\nu_e$ asymmetry (0.8)
in Super K
enhanced by matter effect

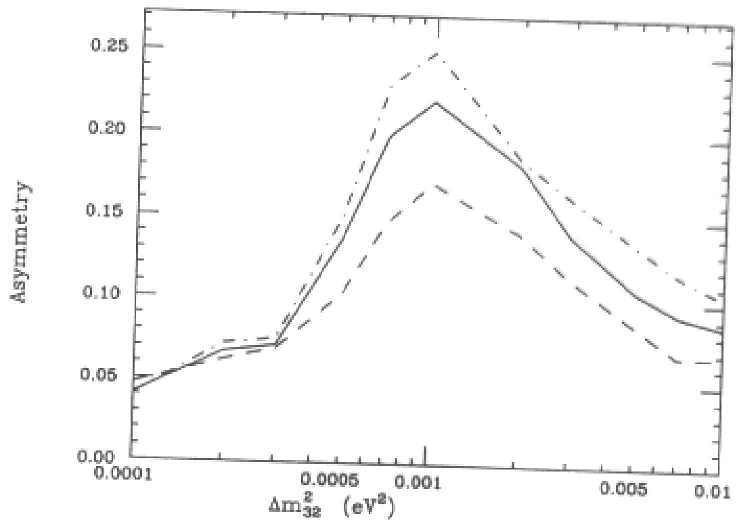



Figure 3c

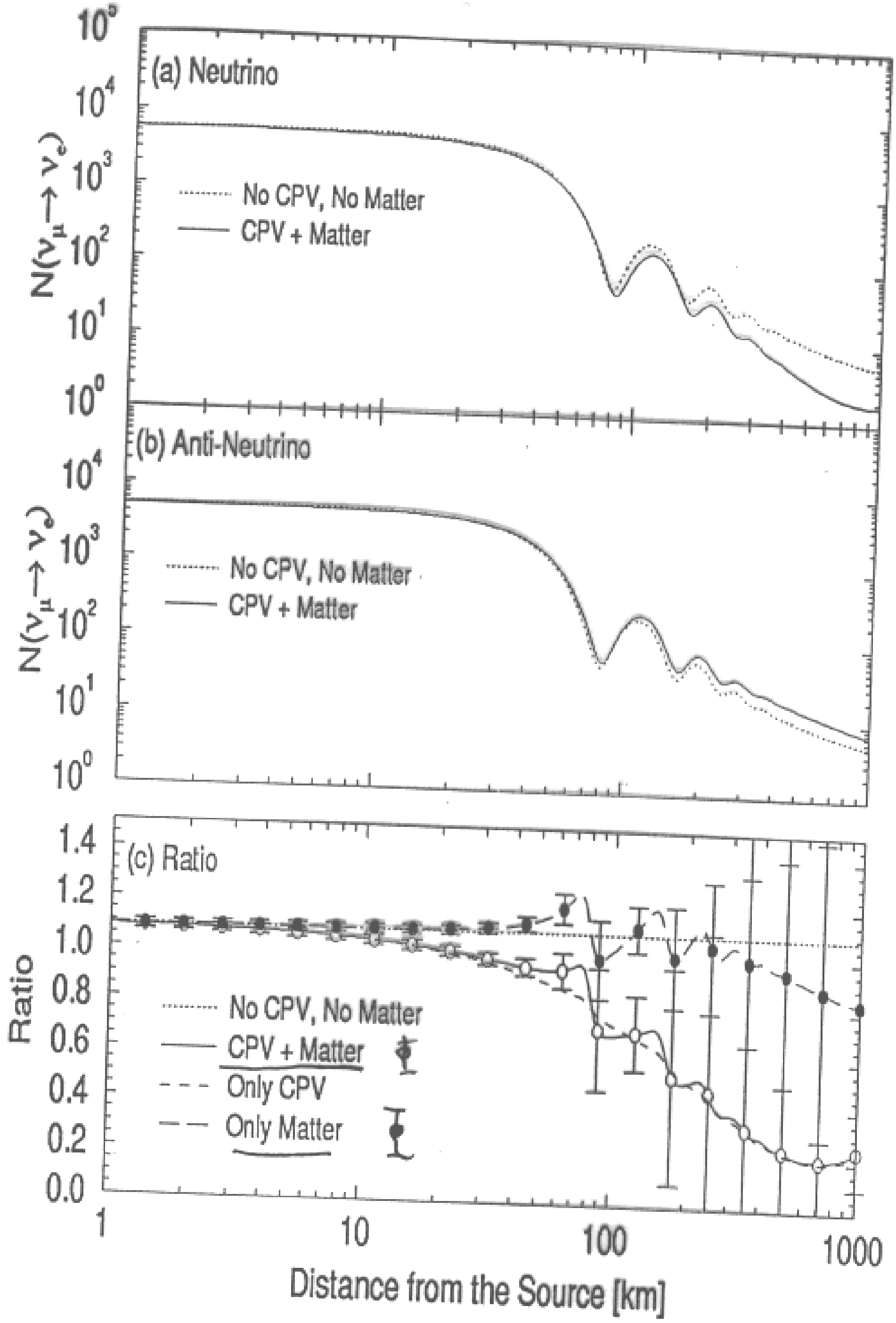
--- $\sin^2 2\theta_{e3} = .03$



Akhmedov ... Smirnov Dighe Lipari
hep-ph 9808270

$$\text{Asymmetry} \equiv \frac{U - D}{(U+D)/2}$$

$U \equiv \cos\theta < -0.8$




Minakata +
Nunokawa
hep-ph 0909
Sept. 2000

$\Delta m^2_{13} = 3 \times 10^{-3}$

$\Delta m^2_{12} = 3 \cdot 10^{-5}$

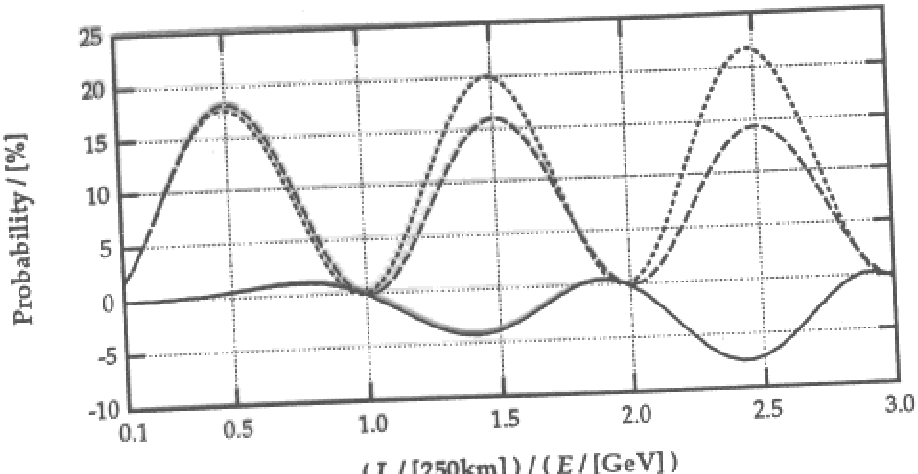
$\sin^2 \theta_{13} = 0.1$

$\delta = \frac{\pi}{2}$

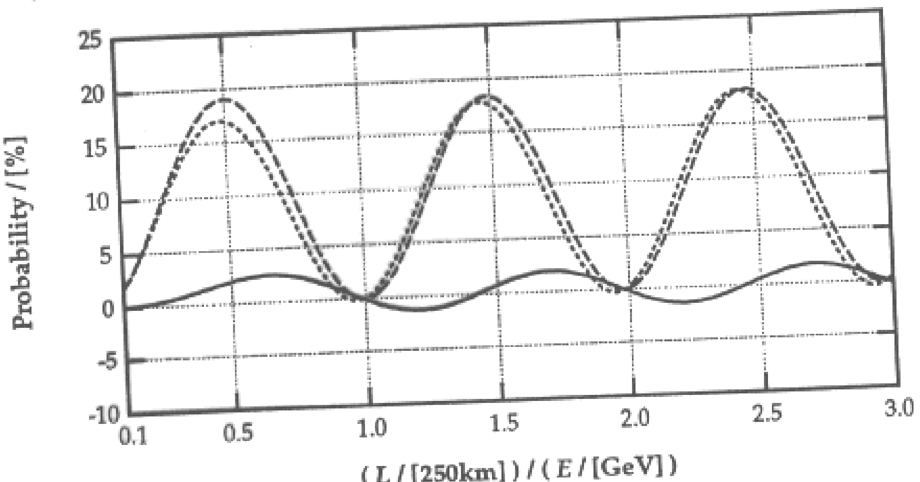
Figure 2. Expected number of events for (a) neutrinos, $N(\nu_\mu \to \nu_e)$, (b) anti-neutrinos, $N(\bar{\nu}_\mu \to \bar{\nu}_e)$, and (c) their ratio $R \equiv N(\nu_\mu \to \nu_e)/N(\bar{\nu}_\mu \to \bar{\nu}_e)$ with a Gaussian type neutrino energy beam with $\langle E_\nu \rangle = 100$ MeV with $\sigma = 10$ MeV are plotted as a function of distance from the source. Neutrino fluxes are assumed to vary as $\sim 1/L^2$ in all the distance range we consider. The mixing parameters as well as the electron number density are fixed to be the same as in Fig. 1. The error bars are only statistical.

JOE SATO






(a) The oscillation probabilities as functions of $L/E$ for $\delta = \pi/2$.




(b) The oscillation probabilities as functions of $L/E$ for $\delta = 0$.

Figure 2: The oscillation probabilities for $\delta = \pi/2$ (Fig.2(a)) and $\delta = 0$ (Fig.2(b)). $P(\nu_\mu \to \nu_e), P(\bar{\nu}_\mu \to \bar{\nu}_e)$ and $\Delta P(\nu_\mu \to \nu_e)$ are given by a broken line, a dotted line and a solid line, respectively. Here $\rho = 2.34\,\mathrm{g/cm^3}$ and $L = 250\,\mathrm{km}$ (the distance between KEK and Super-Kamiokande) are taken. Other parameters are fixed at the following values which are consistent with the solar and atmospheric neutrino experiments [11]: $\delta m^2_{21} = 10^{-4}\,\mathrm{eV}^2, \delta m^2_{31} = 10^{-2}\,\mathrm{eV}^2, s_\psi = 1/\sqrt{2}, s_\phi = \sqrt{0.1}$ and $s_\omega = 1/2$.

# TIME REVERSAL VIOLATION
# at a Neutrino Factory

$$\nu_\mu \; (\bar{\nu}_e) \longrightarrow \nu_e$$
$$\nu_e \; (\bar{\nu}_\mu) \longrightarrow \nu_\mu$$

Difference $\approx$

$$J \sin\frac{\Delta_2}{2} \sin\frac{\Delta_3}{2} \sin\frac{\Delta_3 - \Delta_2}{2}$$

$$\Delta_i = \left(\frac{m_i^2 - m_1^2}{2E}\right) t$$

$J$ = Jarlskog invariant

$$\approx \frac{1}{4} \; s_{13} \sin\delta \; \sin 2\theta_{12}$$

# NEUTRINOLESS $\beta\beta$ DECAY

$$^{76}Ge \rightarrow {}^{76}Se + e^- + e^-$$

$$m_{ee} = |U_{e3}|^2 m_3 + |U_{e2}|^2 \eta_2 m_2 + |U_{e1}|^2 \eta_1 m_1$$

If CP is conserved

$$\eta_2 = \pm 1 \qquad \eta_1 = \pm 1$$

If CP is violated

$$\eta_2 = e^{2i\alpha_2} \qquad \eta_1 = e^{2i\alpha_1}$$

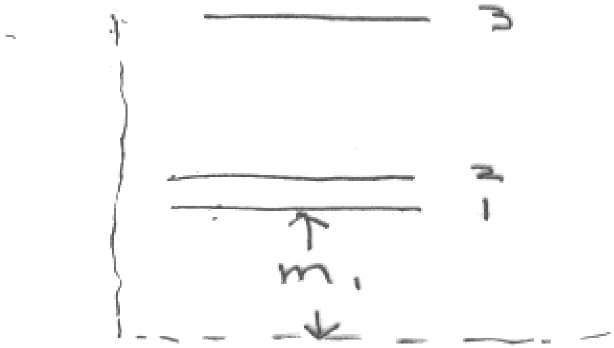
$\alpha_1, \alpha_2$ are "Majorana" phases

Oscillations could determine $J$

(Jarlskog invariant) not $\alpha_1, \alpha_2$

3 Phase invariants: Nieves and Pal Phys. Rev D 36, 315 (1987)

GIVEN $|U_{ei}|^2$ and VALUES of $\Delta m^2$ what can you LEARN FROM $\beta\beta$




$m_{ee} = f(m_1, \alpha_2, \alpha$

$CP \therefore \alpha_i = 0, \frac{\pi}{2}$

$m_{ee}$ DETERINES RANGE of VALUES for $m_1$

No INFORMATION ON CP VIOLATING PHASES

BILENKY, PASCOLI, PETCOV

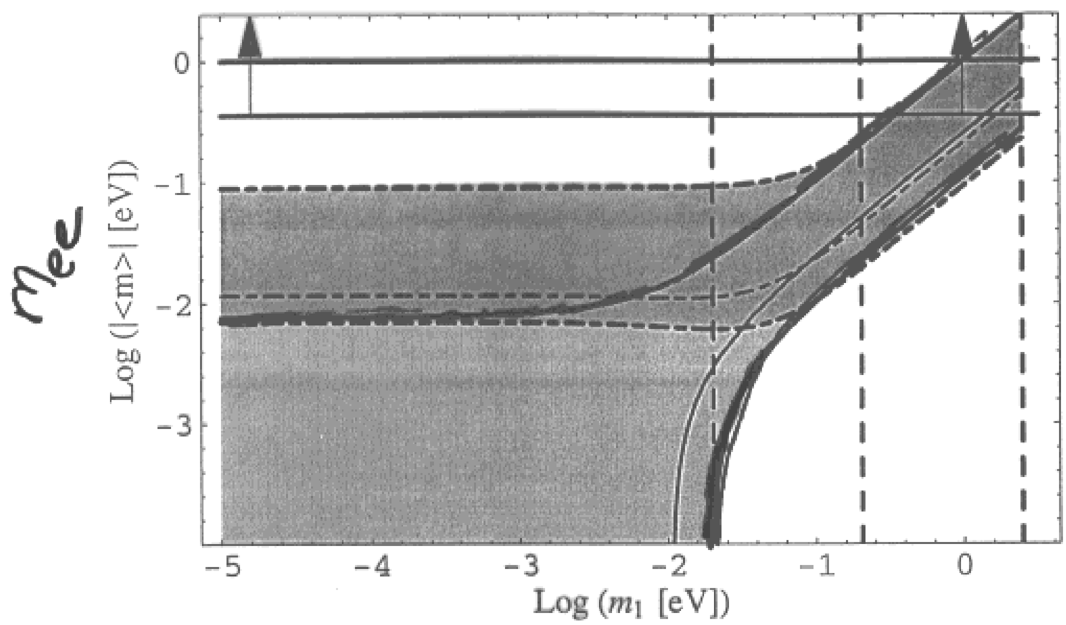



Figure 28: The dependence of $|<m>|$ on $m_1$ *i)* for $\Delta m^2_\odot \ = \Delta m^2_{21}$ and using the results of the analysis of ref. [7] for the LMA solution (light grey and dark grey region between the two doubly thick solid lines) and for the LOW-QVO solution (light grey and dark grey region between the upper doubly thick solid line and the thick solid line), and *ii)* for $\Delta m^2_\odot \ = \Delta m^2_{32}$ and in the case of the LMA solution (dark grey region between the two doubly thick dash-dotted lines) and the LOW-QVO solution (dark grey region between the upper doubly thick dashed-dotted line and the thick dashed-dotted line). The upper bound of ref. [27] on $|<m>|$ , eq. (3), is shown by the horizontal upper doubly thick solid lines. The regions separated by the vertical dashed lines correspond to *i)* $m_1 \ll 0.02$ eV , i.e., hierarchical and inverted hierarchy neutrino mass spectrum, *ii)* 0.02 eV $\leq m_1 \leq 0.2$ eV , i.e., partial hierarchy and partial inverted hierarchy spectrum and to *iii)* the $m_1 \geq 0.2$ eV , i.e., quasi-degenerate spectrum.