S. Bilenky (Dubna)

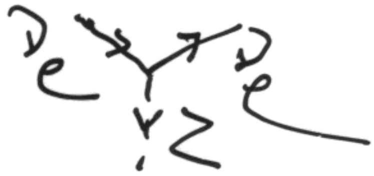
Sterile neutrinos?

Flavour neutrinos

interact with matter via standard CC and NC –

$$j_\alpha^{CC} = 2\sum \bar{\nu}_{lL}\gamma_\alpha l_L$$

$$j_\alpha^{NC} = \sum \bar{\nu}_{lL}\gamma_\alpha \nu_{lL}$$



determined by weak interaction

...ree flavour neutrinos ...xist in nature

$n_\nu = 2.994 \pm 0.012$ (LEP)

Th... ex...

<u>are flavor neutrinos mixed</u>
<u>with sterile</u> (no SM interaction)

Depends on neutrino mass term
(model)

Mass term has the form

$$\mathcal{L}^M = -\bar{n}_R M n_L + h.c.$$

<u>Two possibilities</u>

I $\quad n_L = \nu_L = \begin{pmatrix} \nu_{eL} \\ \nu_{\mu L} \\ \nu_{\tau L} \end{pmatrix}$ $\quad M \to 3\times 3$ matrix

For the mixing

$$\nu_{\ell L} = \sum_{i=1}^{3} U_{\ell i}\, \nu_{iL}$$

only $\nu_\ell \to \nu_{\ell'}$, no sterile

i $\quad n_R = \nu_R = \begin{pmatrix} \nu_{eR} \\ \nu_{\mu R} \\ \nu_{\tau R} \end{pmatrix}$

$L = L_e + L_\mu + L_\tau$ is conserved

<u>ν_i are Dirac particles</u>

(ii) $n_R = (\nu_L)^c$

no conserved lepton numbers

ν_i is Majorana particle

(II)

$$n_L = \begin{pmatrix} \nu_{eL} \\ \nu_{\mu L} \\ \nu_{\tau L} \\ \nu_{s_1 L} \\ \vdots \end{pmatrix} \begin{matrix} \uparrow \\ 3 \\ \downarrow \\ \uparrow \\ n_s \\ \downarrow \end{matrix} \leftarrow \text{bejond the SM}$$

$\nu_{s_i L} = (\nu_{s_i R})^c$ susy, ... particles can be mixed with $\nu_{\ell L}$

$$n_R = (n_L)^c$$

M is $(3+n_s)\times(3+n_s)$ matrix

Mixing

$$\nu_{\ell L} = \sum_{i=1}^{3+n_s} U_{\ell i}\, \nu_{iL}$$

$$\nu_{sL} = \sum_{i=1}^{3+n_s} U_{si}\, \nu_{iL}$$

3 flavour ν's
n_s sterile ν's $\rightarrow 3 + n_s$ massive

$n_s = 3$ natural

n_s can be less than 3 or more

if m_i are small
due to mixing
$\nu_l \to \nu_{l'}$, <u>and</u> $\nu_l \to \nu_s$

<u>Possible ways to reveal the existence of sterile neutrinos</u>

1. to prove that the number of $\nu_i > 3$.

2. to prove that

$$\sum_{l'=e,\mu,\tau} P(\nu_l \to \nu_{l'}) < 1 \quad l = e \text{ or } \mu$$

requires NC detection

From existing data

$\Delta m^2_{solar} \simeq 10^{-5}\, eV^2$ $(\sim 10^{-10}\, eV^2)$

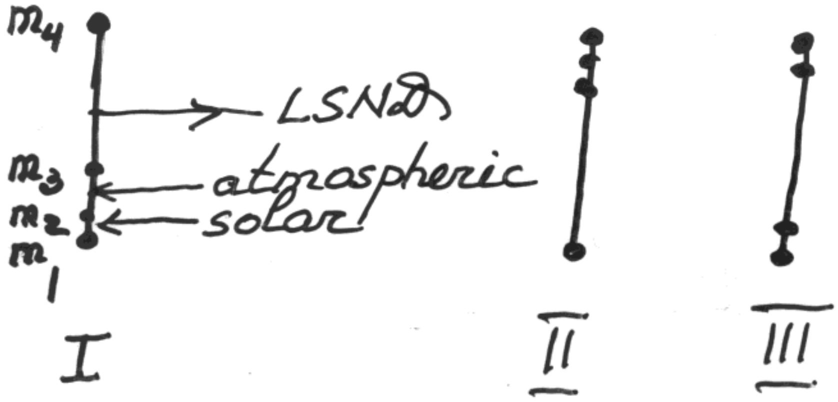
$\Delta m^2_{atm} \simeq 10^{-3}\, eV^2$

$\Delta m^2_{LSND} \simeq 1\, eV^2$

if LSND will be confirmed we need ≥ 4 massive neutrinos
$\longrightarrow$ sterile

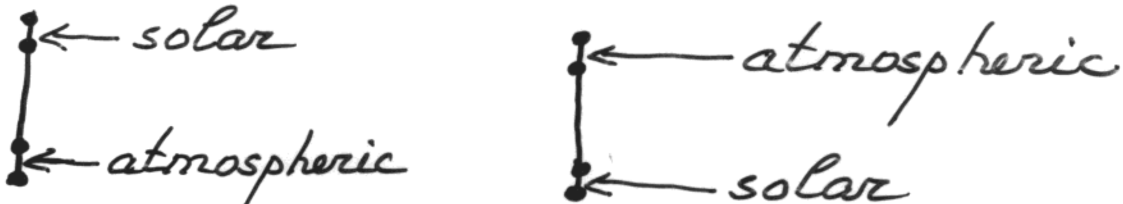
Minimal scheme with 4 ν_i

Caldwell, Mohapatra
Valle, Pieltoniemi
Barger, . . .
C. Giunti, W. Grimus
S. Bilenky



I and II : $\nu_\mu \to \bar{\nu}_e$ strongly suppressed
not compatible with LSND

Two schemes with the spectrum of
the type III



A B

A, B distinguishible

A; $m_T \simeq m_4$
$|\langle m\rangle| \le m_4$

B. $m_T \ll m_4$
$|\langle m\rangle| \ll m_4$

onsider A
ntroduce

$$C_\alpha = \sum_{i=1,2} |U_{\alpha i}|^2 \qquad \alpha = e, \mu, \tau$$

om SBL reactor $\bar{\nu}_e \to \bar{\nu}_e$ and
elerator $\nu_\mu \to \nu_\mu$ (with solar
d atmospheric constraints)

$$C_e \le 4 \cdot 10^{-2} \quad 1 - C_\mu \le 2 \cdot 10^{-1}$$

at $\Delta m^2_{41} \ge 2 \cdot 10^{-1}\,\mathrm{eV}^2$ (LSND)

C
I
Fr
acc
an

From BBN ($n_{eff} < 4$)

$c_s \ll 1$

From unitarity

$$\sum_{\alpha = e,\mu,\tau,s} c_\alpha = 2 \qquad c_\alpha = \sum_{i=1,2} |U_{\alpha i}|^2$$

up to small terms ($< 10^{-1}$)

$c_e \simeq 0 \quad c_\mu \simeq 1 \quad c_s \simeq 0 \quad c_\tau \simeq 1$

Unitary matrix

$$U \simeq \begin{array}{c} \nu_e \\ \mu \\ \tau \\ s \\ \\ \end{array} \begin{array}{c} \begin{pmatrix} 0 & 0 & \cos\theta & \sin\theta \\ \cos\gamma & \sin\gamma & 0 & 0 \\ -\sin\gamma & \cos\gamma & 0 & 0 \\ 0 & 0 & -\sin\theta & \cos\theta \end{pmatrix} \\ \underbrace{1 \quad\quad 2}_{\text{atmospheric}} \quad \underbrace{3 \quad\quad 4}_{\text{solar}} \end{array}$$

Approximate decoupling of atmospheric and solar sectors

__atmospheric__ (mainly) $\underline{\nu_\mu \to \nu_\tau}$

__solar__ (mainly) $\underline{\nu_e \to \nu_s}$

same in A and B

Tests of $\nu_e \to \nu_s$ in solar experiments

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need NC

SNO $\nu + d \to \nu + n + p$

$E_{th} = 2.2$ MeV $\to$ ^8B neutrinos

$$\phi_B(E) = X(E)\,\phi_B$$

$\hookrightarrow$ known function

$$\therefore N^{NC} = \langle \sum_{\ell = e,\mu,\tau} P(\nu_e \to \nu_\ell) \rangle_{\nu d}\ \bar{\sigma}^{NC}_{\nu d}\ \phi_B$$

$$\bar{\sigma}^{NC}_{\nu d} \simeq 4.7 \cdot 10^{-43}\ cm^2$$

$\langle \sum_{\ell = e,\mu,\tau} P(\nu_e \to \nu_\ell) \rangle_{\nu d} < 1$ (?)

need to know ϕ_B.

another information on $\sum_{\ell = e,\mu,\tau} P(\nu_e \to \nu_\ell)$

from $\nu + e \to \nu + e$

(S-K ; SNO)

$$N_{\nu e} = \underbrace{\int_{E_{th}} \left(\sigma_{\nu_e e} - \sigma_{\nu_\mu e}\right) \phi_{\nu_e}\, dE}_{\Sigma_{\nu e}} + \underbrace{\sum_{l=e,\mu,\tau} \langle P(\nu_e \to \nu_l) \rangle_{\nu e}\, \bar{\sigma}_{\nu_\mu e}}_{\text{NC contribution}}$$

$$\bar{\sigma}_{\nu_\mu e} = 2 \cdot 10^{-45}\ \mathrm{cm}^2$$

$\phi_{\nu_e}(E)$ will be determined from SNO CC

$$\nu_e + d \to e^- + p + p$$

$\Sigma_{\nu e}$ can be determined from S-K and SNO

$$R = \frac{\Sigma_{\nu e}\ \bar{\sigma}^{NC}_{\nu d}}{N^{NC}\ \bar{\sigma}_{\nu_\mu e}} = \frac{\langle \sum_{l=e,\mu,\tau} P(\nu_e \to \nu_l) \rangle_{\nu e}}{\langle \sum_{l=e,\mu,\tau} P(\nu_e \to \nu_l) \rangle_{\nu d}}$$

no dependence on ϕ_B

if $R \neq 1$ transitions

$$\nu_e \to \nu_s$$

from spectrum measurement

$$\frac{\overset{\text{measured}}{\Sigma_{\nu e}(T)}}{\underbrace{\frac{d\bar{\sigma}_{\nu e}}{dT}}_{\text{known function}}} = \langle \sum_{l=e,\mu,\tau} P(\nu_e \to \nu_l) \rangle_T \, \phi_B$$

if lhs depends on T, transition $\nu_e \to \nu_s$

Fig.

Test of $\nu_\mu \to \nu_s$ in atmospheric neutrinos

NC events — M. Goldhaber, Y. Suzuki, ...

$$\nu + N \to \nu + \pi^0 + X$$

two-ring events

up-down asymmetry

$$A_{NC} = \left(\frac{U - D}{U + D}\right)_{\pi^0}$$

if $\nu_\mu \to \nu_\tau$ $\quad A_{NC} = 0$

if $\nu_\mu \to \nu_s$ $\quad A_{NC} = \dfrac{-\sin^2 2\theta}{(4 - \sin^2 2\theta) + 4\frac{1}{r}}$

$r = \dfrac{N^0_{\nu_\mu}}{N^0_{\nu_e}}$, For $2 \le r \le 3$, $\sin^2 2\theta \simeq 1$ — Learned, Pakvasa

$A_{NC} \simeq -0.2$

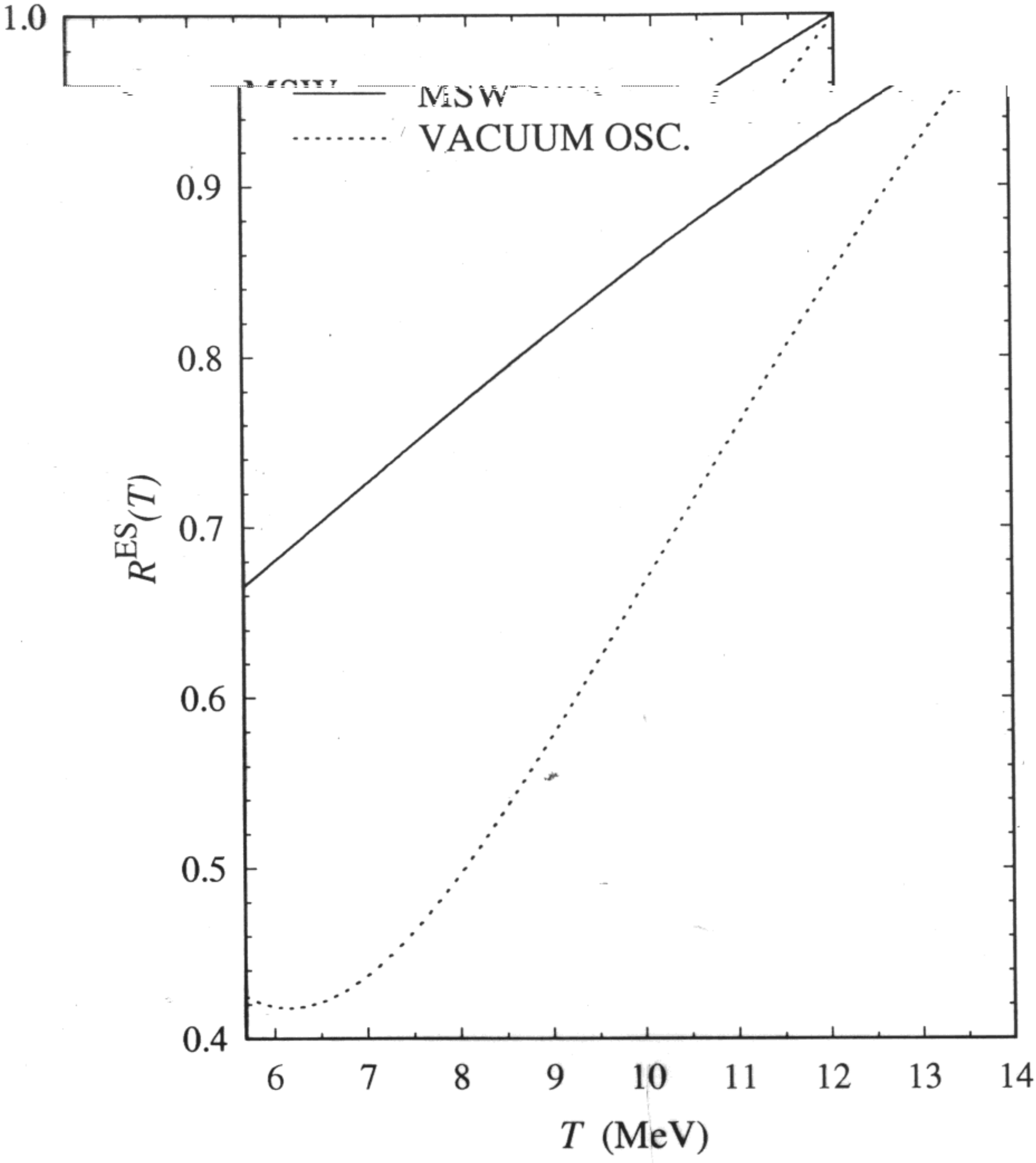

Figure 1

Conclusions

F= ~

1. It is difficult but possible to check $\nu_\ell \to \nu_s$

2. From phenomenological point of view $\nu_\ell \to \nu_s$ ($\nu_e \to \nu_s$) depend on correctness of LSND.
(the problem of sterile neutrino is [illegible] the problem of LSND.)

3. I do not know why light sterile neutrinos are necessary for the theory