2/18/00
Fermilab

Nu Scenarios

Stephen Parke – FNAL

- Atmospheric / Solar / LSND
- 3 Active Nu Scenarios
- 3 Active, 1 light Sterile Nu Scenario

NEUTRINO OSCILLATION EVIDENCE

Atmospheric: (ν_μ dissappearance)

$$\Delta m^2 \sim 3 \times 10^{-3}\, eV^2$$

near maximal mixing
(zenith angle dependance)

Solar: (ν_e dissappearance)

$$\Delta m^2 \lesssim 10^{-5}\, eV^2$$

near maximal mixing*
(* maybe with MSW enhancement)

(many exp. — no neutrino oscillation "smoking gun")

LSND: ($\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ ν_e appearance)

$$\Delta m^2 \sim 1\, eV^2$$

small mixing angle:
(confirmation - MBOONE and KARMEN)

UNLIKELY that <u>all</u> of these results will stand the test of time.

3 Active Neutrinos

⇒ ① Atmospheric / Solar

② Atmospheric / LSND

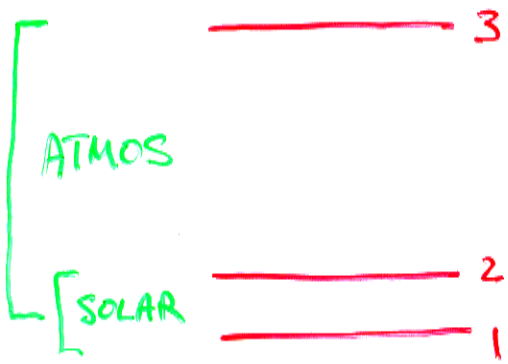
③ Atmospheric / LSND / Solar

— Distinguished by χ^2

3 Active / 1 light Sterile

⇒ ① Atmospheric / LSND / Solar

3 Active: Atmospheric / Solar



- Atmospheric $\nu_\mu \leftrightarrow \nu_\tau$ Maximal
- small "e" component in "3"
- Atmospheric LA, SA, Low Mass MSW

- LSND major contributor to χ^2 for this scenario.

3 Active Neutrino Scenarios to be considered are the following with CP violation, $\delta = 0$ or $\pi/2$.

- Scenario IA:

Large Mixing Angle MSW Solar –OR–
Small Mixing Angle MSW Solar –OR–
LOW Mass MSW Solar

$$\Delta m^2_{23} = 3.5 \times 10^{-3}\ \text{eV}^2, \qquad \sin^2 2\theta_{23} = 1.0$$
$$\Delta m^2_{13} = 3.5 \times 10^{-3}\ \text{eV}^2, \qquad \sin^2 2\theta_{13} = 0.04$$

below CHOOZ

LMA-MSW $\Delta m^2_{12} = 5 \times 10^{-5}\ \text{eV}^2, \qquad \sin^2 2\theta_{12} = 0.8$

SMA-MSW $\Delta m^2_{12} = 6 \times 10^{-6}\ \text{eV}^2, \qquad \sin^2 2\theta_{12} = 0.006$

LOW MSW $\Delta m^2_{12} = 1 \times 10^{-7}\ \text{eV}^2,$ * $\qquad \sin^2 2\theta_{12} = 0.9$

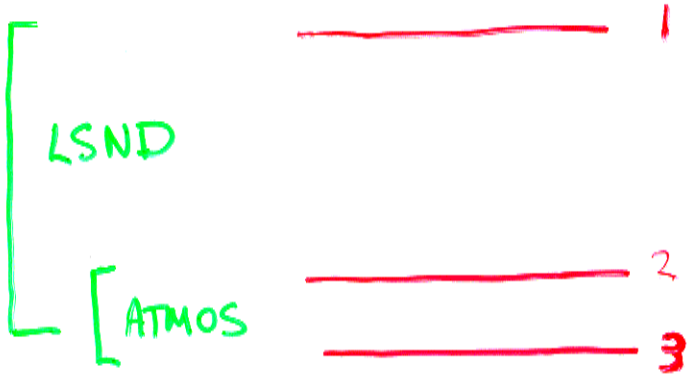
where this choice corresponds to effective two-component "mixing angles" given by

$\sin^2 2\theta_{atm} = 0.98, \ \sin^2 2\theta_{reac} = 0.04,$

$\sin^2 2\theta_{sol} = 0.78, \ \sin^2 2\theta_{sol} = 0.006, \ \sin^2 2\theta_{sol} = 0.88$

* expect little sensitivity to Δm^2_{12} this small.
— JUST SO would give similar results for terrestial exp.

3 Active: Atmospheric / LSND



- "1" primarily "e"
- Atmospheric $\nu_\mu \leftrightarrow \nu_\tau$ maximal mixing
- Solar exp. major contributors to χ^2 for this scenario.

– MATTER EFFECTS SMALL: $\frac{\Delta m^2}{E} \gg 2\sqrt{2} G_F N_e$, $E \sim 50$ GeV

– HOWEVER CP VIOLATION EFFECTS LARGER:

- Scenario IB1:

$$\Delta m^2_{23} = \Delta m^2 = 3.5 \times 10^{-3}\ \text{eV}^2, \quad \sin^2 2\theta_{23} = 1.0$$
$$\Delta m^2_{13} = \Delta m^2 + \Delta M^2 \simeq 0.3\ \text{eV}^2, \quad \sin^2 2\theta_{12} = 0.015$$
$$\Delta m^2_{12} = \Delta M^2 = 0.3\ \text{eV}^2, \quad \sin^2 2\theta_{13} = 0.015$$

$\delta = 0$ or $\pi/2$

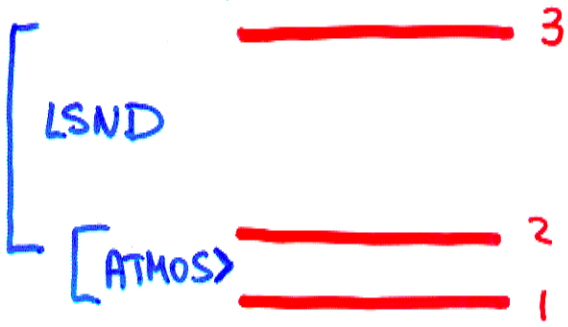
where this choice corresponds to effective two-component "mixing angles" given by

$$\sin^2 2\theta_{atm} = 0.99, \ \sin^2 2\theta_{reac} = 0.03, \ \sin^2 2\theta_{LSND} = 0.03$$

3 Active:

Atmos / LSND / Solar

Barenboim + Scheck hep-ph/980827 / Stancu hep-ph/9903552



- Atmospheric a combination of $\nu_\mu \leftrightarrow \nu_\tau$ and $\nu_e \leftrightarrow \nu_\mu$
- Solar $\sim 1/2$ fluxes $\sin^2\left(1.27 \frac{\Delta m^2 L}{E}\right) \sim 1/2$

- Major contributors to χ^2; Atmospheric as well as Chlorine in Solar experiment ($\sim 1/3$)

- Scenario IC1:

just below CHOOZ for $\nu_e \to \nu_x$ since mixing is large

$$\Delta m^2_{12} = \Delta m^2 = 0.7 \times 10^{-3}\ \text{eV}^2, \qquad \sin^2 2\theta_{12} = 0.89$$
$$\Delta m^2_{23} = \Delta m^2 + \Delta M^2 \simeq 0.3\ \text{eV}^2, \qquad \sin^2 2\theta_{23} = 0.53$$
$$\Delta m^2_{13} = \Delta M^2 = 0.3\ \text{eV}^2, \qquad \sin^2 2\theta_{13} = 0.036$$

$\delta = 0$ or $\pi/2$

Light Sterile Neutrinos

- Preferred # by Theorists: $\emptyset$

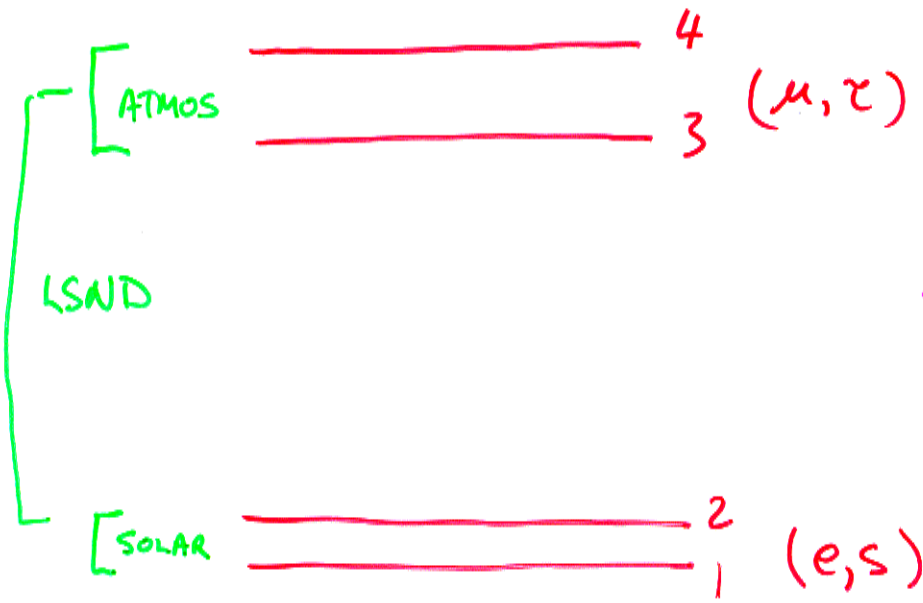
- Hard to have just 1 light Sterile Neutrino

- Why not a 3 light Sterile Neutrino scenario?

  — many, many parameters.

This 3 Active / 1 light Sterile scenario is an illustrative example:

3 Active + 1 light Sterile Neutrino



- Many parameters can fit observations

- Major Contribution to χ^2 coming from Theorists!

Why only 1 light sterile? Mass degeneracy?

- Scenario IIB1:

  Mid-range LSND ΔM^2,
  small Atmospheric Δm^2,
  small angle MSW for Solar
  with or without CP violation

$$\Delta m^2_{34} = \Delta m^2 = 3.5 \times 10^{-3}\ \text{eV}^2, \qquad \sin^2 2\theta_{34} = 1.0$$
$$\Delta m^2_{12} = 6 \times 10^{-6}\ \text{eV}^2, \qquad \sin^2 2\theta_{12} = 0.006$$
$$\Delta m^2_{14} \simeq \Delta m^2_{13} \simeq \Delta m^2_{24} \simeq \Delta m^2_{23} \equiv \Delta M^2 = 0.3\ \text{eV}^2$$
$$\sin^2 2\theta_{14} = \sin^2 2\theta_{13} = \sin^2 2\theta_{24} = \sin^2 2\theta_{23} = 0.03$$
$$\delta_1 = 0,\ \delta_2 = 0 \text{ or } \pi/2,\ \delta_3 = 0$$

which corresponds to effective two-component "mixing angles"

$\sin^2 2\theta_{ATM} = 1.0,\ \sin^2 2\theta_{SOL} = 0.006,\ \sin^2 2\theta_{LSND} \simeq 0.03$

STANCU —

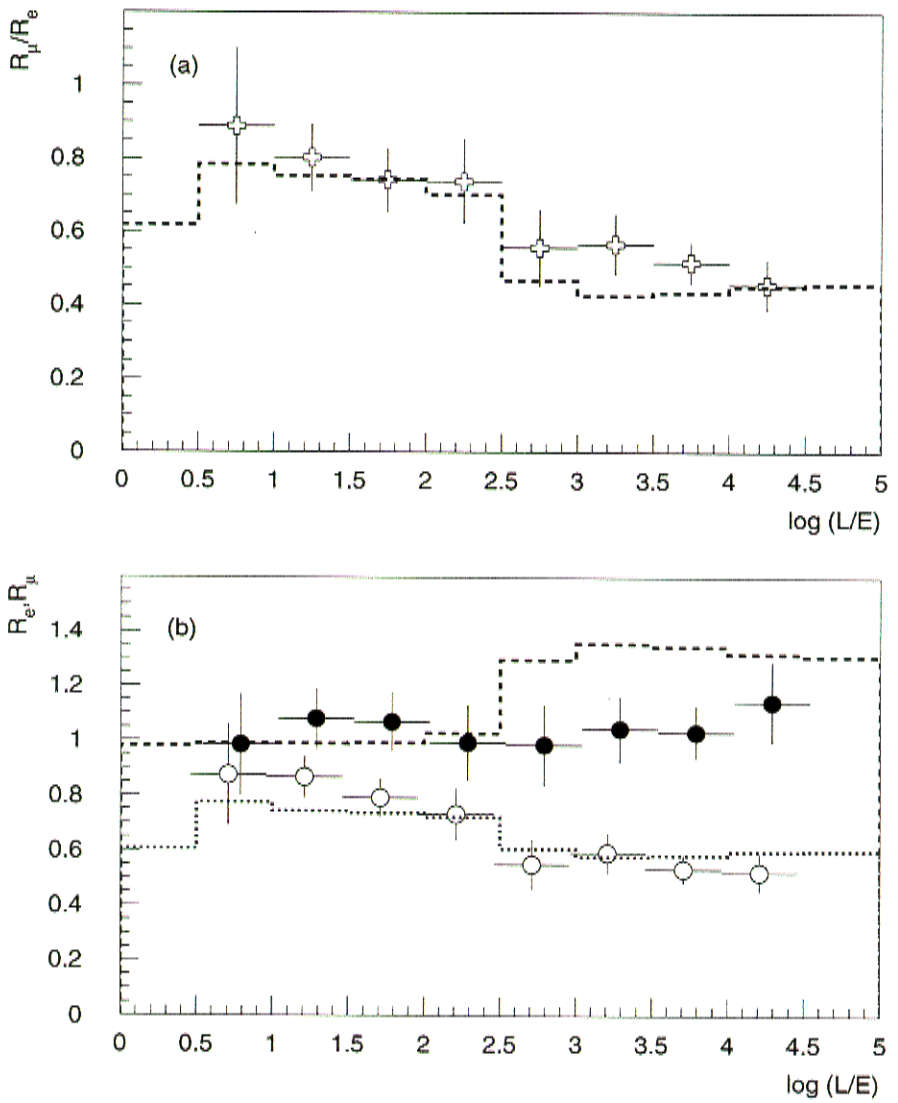


Fig. 4. (a) The predicted ratio of ratios (R_μ/R_e) versus $\log(L/E)$ – dashed histogram – compared to the Super-Kamiokande data (empty crosses with error bars). (b) The predicted μ-like (dotted) and e-like (dashed) event ratios (R_μ and R_e) versus $\log(L/E)$, compared to the Super-Kamiokande data (full and empty circles with error bars, respectively) scaled by a factor of 0.87. Both (a) and (b) have been obtained with $\Delta m^2 = 10^{-3}$ eV^2 and $\Delta M^2 = 0.45$ eV^2.

SUMMARY:

5 × 3 Active Neutrinos

3 standard + 2 more exotic

1 × 3 Active + 1 light sterile

— SCENARIOS —

but beware of surprises:

— LSND confirmed by BOONE

— SMA-MSW solution RULED OUT for solar