FOUR-NEUTRINO OSCILLATIONS AND THE SOLAR NEUTRINO PROBLEM

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- 4ν MIXING - WHY? HOW?
- ALLOWED 4-ν SCHEMES
- FIT OF SOLAR NEUTRINO DATA

(hep-ph/0001101)

4ν MIXING - WHY?

THREE INDICATIONS OF ν OSCILLATIONS:

1- SOLAR $\nu_e \to \nu_\mu, \nu_\tau$ AND/OR $\nu_e \to \nu_s$

$\Delta m^2_{SUN} \sim 10^{-10}\,eV^2$ (VO) $\sim 10^{-5}$-$10^{-4}\,eV^2$ (MSW)

2- ATMOSPHERIC $\nu_\mu \to \nu_\tau$ AND/OR $\nu_\mu \to \nu_s$

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

3- LSND $\nu_\mu \to \nu_e$ APPEARANCE!

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

THREE Δm^2 $\Longrightarrow$ AT LEAST FOUR LIGHT MASSIVE NEUTRINOS!

$Z^0 \to \nu\bar{\nu} \Longrightarrow \nu_e \quad \nu_\mu \quad \nu_\tau$

FLAVOR NEUTRINOS

IN GENERAL FLAVOR NEUTRINOS ARE NOT MASS EIGENSTATES

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k}\, \nu_{kL} \qquad (\alpha = e, \mu, \tau)$$

$\nu_k \to m_k$ $\qquad n \geq 3$

$n = 4 \Longrightarrow \nu_1 \quad \nu_2 \quad \nu_3 \quad \nu_4$ MASS BASIS

$\nu_e \quad \nu_\mu \quad \nu_\tau \quad \nu_s$ FLAVOR BASIS

MINIMAL CHOICE COMPATIBLE WITH ALL DATA

OCCAM'S RAZOR: PLURALITAS NON EST PONENDA SINE NECESSITATE

STERILE NEUTRINO

4ν MIXING - HOW?

NO PROBLEM!

MANY MODELS AVAILABLE

PROBLEM!

TOO MANY MODELS AVAILABLE
(ALL "AD HOC")

OUR APPROACH:

PHENOMENOLOGICAL
(GET INFO ON 4ν MIXING FROM DATA)

4ν COMPLICATED BUT VERY INTERESTING FOR THEORY AND EXPERIMENT

- STERILE ν IS <u>FAR</u> BEYOND THE SM!
- MANY OSCILLATION CHANNELS, HIGH Δm^2 FOR SBL, CP VIOLATION IN LBL AND νFACT
- MORE EXOTIC PHENOMENA? (DECAY, MAGNETIC MOMENT, ...)

THEORETICAL MODELS

PROBLEM: MAKE THE STERILE ν LIGHT

(INCOMPLETE LIST)

- ν_S = LIGHT NEUTRAL FERMION COMING FROM

  - NEW SYMMETRIES + HIGGSES + FERMIONS
    PELTONIEMI + VALLE (1993), CALDWELL + MOHAPATRA (1993
    MA + ROY (1995), MA (1996), GAUR + GHOSAL + MA + ROY (1998),
    UTPAL SARKAR (1999), GRIMUS + PFEIFFER + SCHWETZ (1999)

  - SUPERSYMMETRY
    CHUN + JOSHIPURA + SMIRNOV (1995),
    JOSHIPURA + SMIRNOV (1998), MA (1999),
    CHUN + KANG + KIM + LEE (1998)

  - SUPERSTRINGS
    BENAKLI + SMIRNOV (1997)

  - MIRROR WORLD
    FOOT + VOLKAS (1992, 1994, 1995),
    BEREZHIANI + MOHAPATRA (1995), FOOT + VOLKAS + YASUDA (1998),
    BRAHMACHARI + MOHAPATRA (1998)

- SINGULAR SEE-SAW
  CHUN + KIM + LEE (1998), LIU + SONG (1998),
  CHIKIRA + HABA + MIMURA (1998)

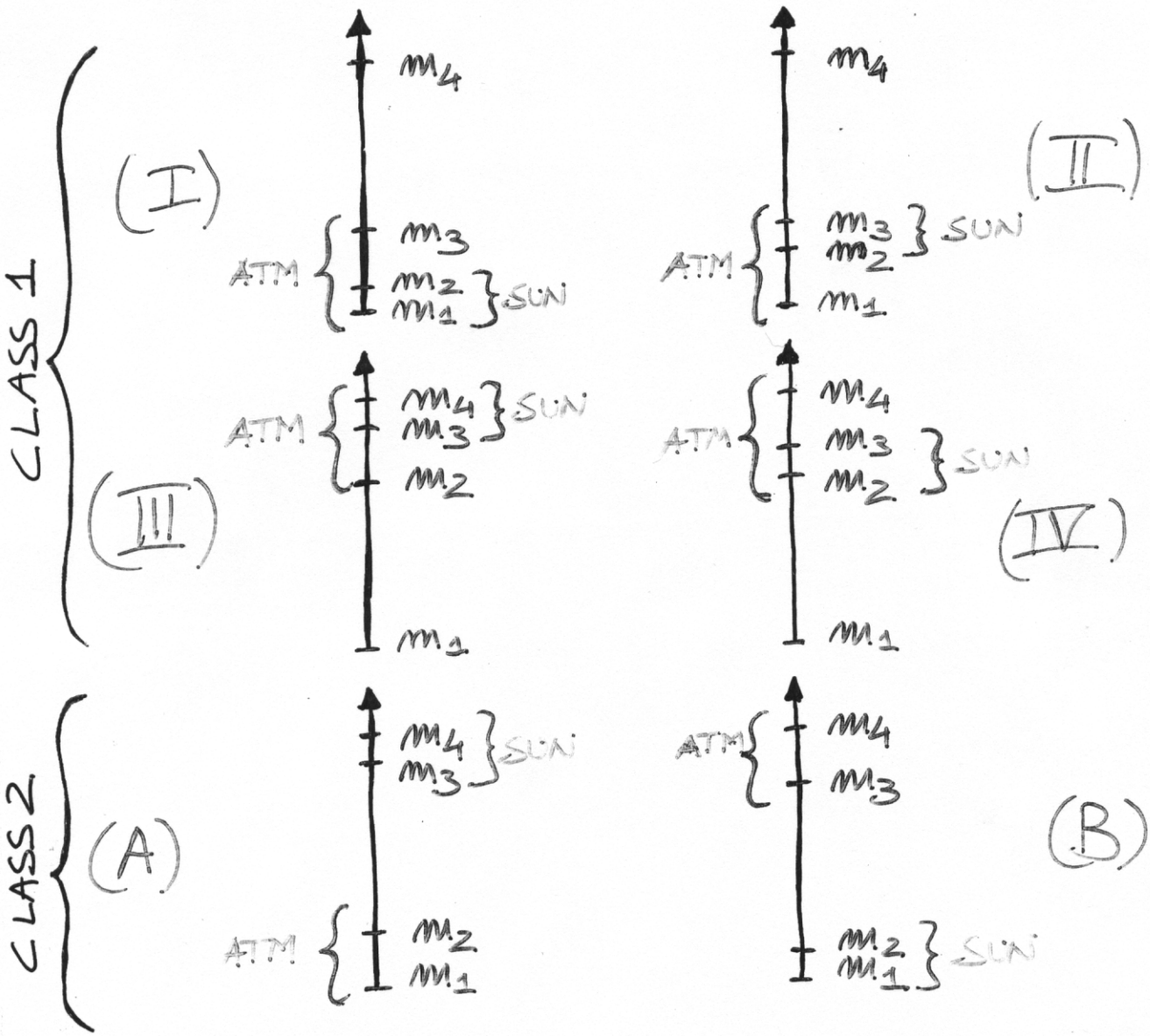
$$M = \begin{pmatrix} 0 & M_D \\ M_D^T & M_R \end{pmatrix}$$

ASSUMPTION:
M_R HAS RANK 2

$$\Delta m^2_{SUN} \ll \Delta m^2_{ATM} \ll \Delta m^2_{LSND}$$

$$\Downarrow$$

ONLY 6 POSSIBLE TYPES OF ν MASS SPECTRA



ν MIXING PARAMETERS

Δm^2_{SUN} Δm^2_{ATM} Δm^2_{SBL}

4x4 MIXING MATRIX

6 MIXING ANGLES

3 CP-VIOLATING PHASES ("DIRAC TYPE")

3 CP-VIOLATING PHASES ("MAJORANA TYPE")

NO EFFECT IN ν OSC.

FIRST APPROXIMATION:

NEGLECT PHASES

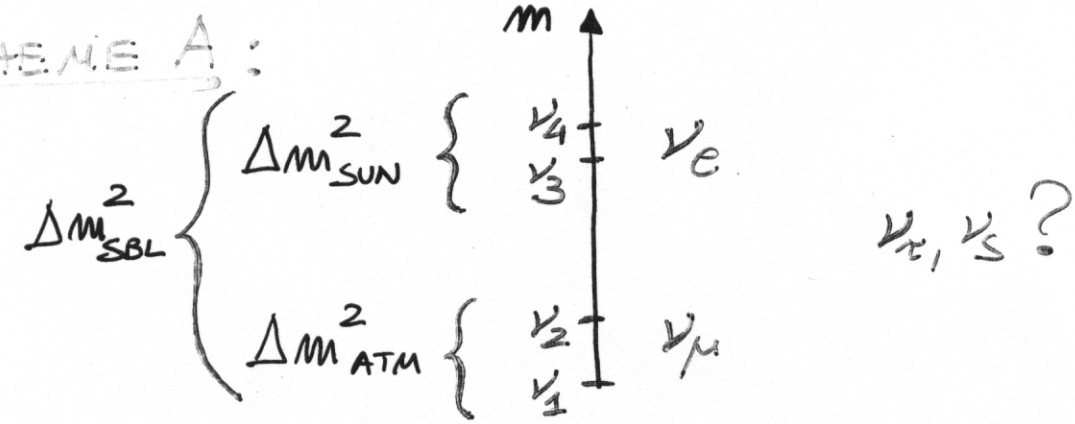
SECOND APPROXIMATION:

NEGLECT SMALL MIXING ANGLES

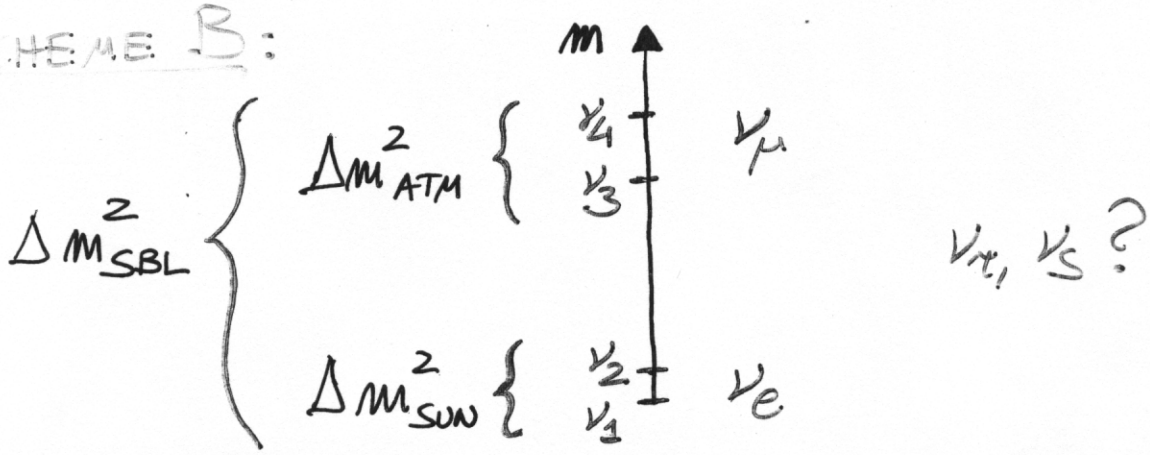
FROM RESULTS OF SBL EXPERIMENTS

FROM THE RESULTS OF NEUTRINO OSCILLATION EXPERIMENTS:

SCHEME A:



SCHEME B:



IMPLICATIONS FOR $(\beta\beta)_{0\nu}$ AND ^3H EXP.:

SCHEME A: "HEAVY ν_e" $\begin{cases} |\langle m \rangle| \lesssim m_4 \\ m(^3H) \simeq m_4 \end{cases}$

SCHEME B: "LIGHT ν_e" $\begin{cases} |\langle m \rangle| \lesssim a_e^0 m_4 \ll m_4 \\ m(^3H) \ll m_4 \end{cases}$

CONSIDER ONLY SCHEME B FOR SIMPLICITY

ALL THAT FOLLOWS IS VALID ALSO IN SCHEME A (WITH APPROPRIATE PERMUTATION OF INDICES)

$$\overbrace{\underbrace{m_1 < m_2}_{\Delta m^2_{SUN}} < \underbrace{m_3 < m_4}_{\Delta m^2_{ATM}}}^{\Delta m^2_{SBL}}$$

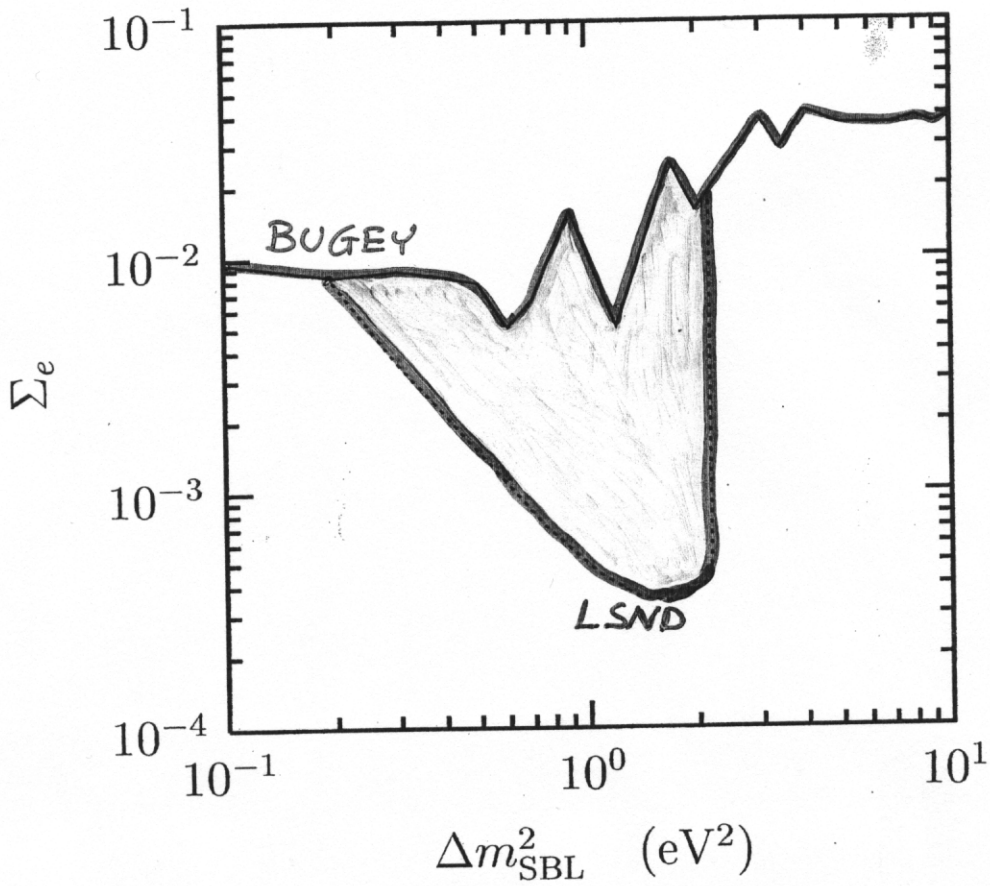
DEFINITION:

$$\Sigma_\alpha \equiv \sum_{k=3,4} |U_{\alpha k}|^2 \qquad (\alpha = e, s, \mu, \tau)$$

QUANTIFIES THE MIXING OF THE FLAVOR NEUTRINO ν_α WITH THE TWO MASSIVE NEUTRINOS WHOSE Δm^2 IS RELEVANT FOR ATMOSPHERIC NEUTRINO OSCILLATIONS

$$(A): \quad \Sigma_e = \sum_{k=1,2} |U_{ek}|^2$$

$$(B): \quad \Sigma_e = \sum_{k=3,4} |U_{ek}|^2$$

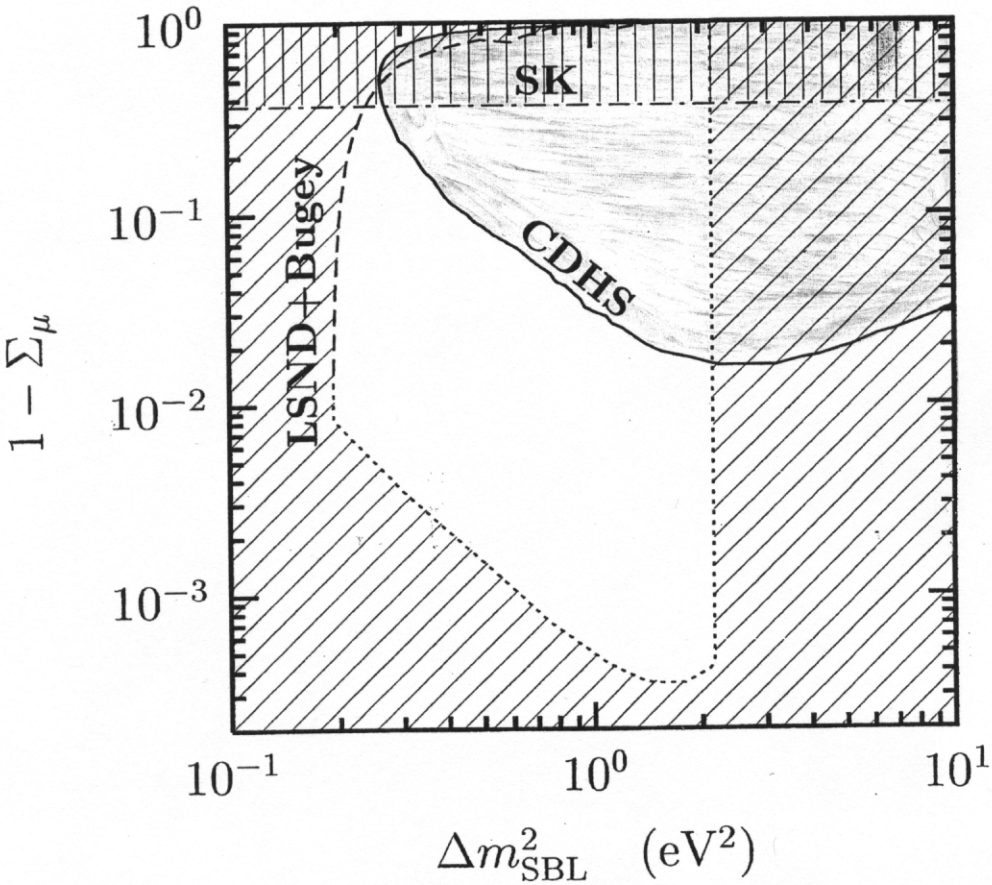


$$\Delta m^2_{SBL} = \Delta m^2_{LSND} = \Delta m^2_{41}$$

C. G., JHEP 01 (2000) 032

(A): $\Sigma_\mu = \sum_{k=1,2} |U_{\mu k}|^2$

(B): $\Sigma_\mu = \sum_{k=3,4} |U_{\mu k}|^2$



C.G., JHEP 01 (2000) 032

4x4 MIXING MATRIX

$$U = V^{(34)} V^{(24)} V^{(23)} V^{(14)} V^{(13)} V^{(12)}$$

(NEGLECT PHASES)

$$V^{(12)} = \begin{pmatrix} c_{12} & s_{12} & 0 & 0 \\ -s_{12} & c_{12} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \ldots$$

$$\Sigma_e \ll 1 \Rightarrow |U_{e3}| \ll 1, \ |U_{e4}| \ll 1$$

$$V^{(13)} = \begin{pmatrix} c_{13} & 0 & s_{13} & 0 \\ 0 & 1 & 0 & 0 \\ -s_{13} & 0 & c_{13} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad V^{(14)} = \begin{pmatrix} c_{14} & 0 & 0 & s_{14} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s_{14} & 0 & 0 & c_{14} \end{pmatrix}$$

$$\Sigma_e \ll 1 \Rightarrow \begin{array}{ll} s_{13} \ll 1 & V^{(13)} \simeq \mathbb{1} \\ s_{14} \ll 1 & V^{(14)} \simeq \mathbb{1} \end{array}$$

$$U = V^{(34)} V^{(24)} V^{(23)} V^{(12)}$$

FOUR MIXING ANGLES!

IRRELEVANT FOR SOLAR NEUTRINOS

$$
U = \begin{array}{c} \\ e \\ s \\ \mu \\ \tau \end{array}
\begin{array}{c}
\begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
\begin{pmatrix}
c_{12} & s_{12} & 0 & 0 \\
-s_{12} c_{23} c_{24} & c_{12} c_{23} c_{24} & s_{23} c_{24} & s_{24} \\
s_{12}(c_{23} s_{24} s_{23} + s_{23} c_{34}) & -c_{12}(s_{23} c_{34} + c_{23} s_{24} s_{34}) & c_{23} c_{34} - s_{23} s_{24} s_{34} & c_{24} s_{34} \\
s_{12}(c_{23} s_{24} c_{34} - s_{23} s_{34}) & c_{12}(s_{23} s_{34} - c_{23} s_{24} c_{34}) & -(c_{23} s_{34} + s_{23} s_{24} c_{34}) & c_{24} c_{34}
\end{pmatrix}
\end{array}
$$

$P^{(SUN)}_{\nu_e \to \nu_e}$ DETERMINED BY θ_{12}

$P^{(SUN)}_{\nu_e \to \nu_s}$, $P^{(SUN)}_{\nu_e \to \nu_\mu, \nu_\tau}$ DETERMINED BY θ_{23}, θ_{24}

θ_{34} IS IRRELEVANT FOR SOLAR NEUTRINOS

(IT DETERMINES THE RATIO $P^{(SUN)}_{\nu_e \to \nu_\mu} / P^{(SUN)}_{\nu_e \to \nu_\tau}$

THAT IS NOT MEASURABLE)

LINEAR COMBINATION OF ν_μ, ν_τ :

$$\begin{pmatrix} \nu_a \\ \nu_b \end{pmatrix} = \begin{pmatrix} -S_\theta & -C_\theta \\ C_\theta & -S_\theta \end{pmatrix} \begin{pmatrix} S_{34} & C_{34} \\ C_{34} & -S_{34} \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix}$$

WITH $\tan\theta = \dfrac{\sin\vartheta_{24}}{\tan\vartheta_{23}}$

$$U_{a1} = -S_{12}\sqrt{1 - C_{23}^2 C_{24}^2} \qquad U_{a2} = C_{12}\sqrt{1 - C_{23}^2 C_{24}^2}$$

$$U_{b1} = U_{b2} = 0 \Rightarrow P^{(SUN)}_{\nu_e \to \nu_b} = 0$$

$P^{(SUN)}_{\nu_e \to \nu_a}$ DEPENDS ON $\boxed{C_{23}^2 C_{24}^2}$

$$C_{23}^2 C_{24}^2 = 1 \Rightarrow U_{a1} = U_{a2} = 0 \Rightarrow P^{(SUN)}_{\nu_e \to \nu_a} = 0$$

$$P^{(SUN)}_{\nu_e \to \nu_s} = 1 - P^{(SUN)}_{\nu_e \to \nu_e}$$

$$C_{23}^2 C_{24}^2 = 0 \Rightarrow U_{a1} = -S_{12}, \; U_{a2} = C_{12}$$

$$P^{(SUN)}_{\nu_e \to \nu_a} = 1 - P^{(SUN)}_{\nu_e \to \nu_e}, \quad P^{(SUN)}_{\nu_e \to \nu_s} = 0$$

$$(U_{s1} = U_{s2} = 0)$$

$$P^{(SUN)}_{\nu_e \to \nu_s} = c_{23}^2 c_{24}^2 \left(1 - P^{(SUN)}_{\nu_e \to \nu_e}\right) \quad \text{STERILE}$$

$$P^{(SUN)}_{\nu_e \to \nu_a} = \left(1 - c_{23}^2 c_{24}^2\right)\left(1 - P^{(SUN)}_{\nu_e \to \nu_e}\right) \quad \text{ACTIVE}$$

VACUUM OSCILLATIONS

$$P^{(SUN)}_{\nu_e \to \nu_e} = 1 - \sin^2 2\vartheta_{12} \sin^2 \frac{\Delta m^2_{21} L}{4E}$$

ONLY ϑ_{12} !

MSW

$$P^{(SUN)}_{\nu_e \to \nu_e} = \frac{1}{2} + \left(\frac{1}{2} - P_c\right) \cos 2\vartheta_{12} \cos 2\vartheta_{12}^M$$

$$\tan 2\vartheta_{12}^M = \frac{\tan 2\vartheta_{12}}{1 - A/\Delta m^2_{21} \cos 2\vartheta_{12}}$$

$$A = \underbrace{A_{CC}}_{2\sqrt{2}\,E G_F N_e} + c_{23}^2 c_{24}^2 \underbrace{A_{NC}}_{-\sqrt{2}\,E G_F N_n}$$

SHIFT THE RESONANCE TO HIGHER MATTER DENSITY (INCREASE STERILE COMPONENT)

RESONANCE: $A_R = \Delta m^2_{21} \cos 2\vartheta_{12}$

(D. DOOLING, C.G., K. KANG, C.W. KIM, PRD 61 (2000) 073011)

REGENERATION IN THE EARTH (MSW REGION)

$$P^{(S+E)}_{\nu_e \to \nu_e} = P^{(SUN)}_{\nu_e \to \nu_e} + \frac{\left(1 - 2\, P^{(SUN)}_{\nu_e \to \nu_e}\right)\left(P^{(EARTH)}_{\nu_2 \to \nu_e} - \sin^2\theta_{12}\right)}{\cos 2\theta_{12}}$$

$$P^{(S+E)}_{\nu_e \to \nu_s} = P^{(SUN)}_{\nu_e \to \nu_s} + \frac{\left(2\, P^{(SUN)}_{\nu_e \to \nu_s} - \underline{c_{23}^2\, c_{24}^2}\right)\left(P^{(EARTH)}_{\nu_2 \to \nu_s} - c_{12}^2\, \underline{c_{23}^2\, c_{24}^2}\right)}{\cos 2\theta_{12}\ \underline{c_{23}^2\, c_{24}^2}}$$

$$P^{(S+E)}_{\nu_e \to \nu_a} = 1 - P^{(S+E)}_{\nu_e \to \nu_e} - P^{(S+E)}_{\nu_e \to \nu_s}$$

EARTH EFFECT: $P^{(EARTH)}_{\nu_2 \to \nu_e}$, $P^{(EARTH)}_{\nu_2 \to \nu_s}$

RELATION: $$P^{(EARTH)}_{\nu_2 \to \nu_s} = \underline{c_{23}^2\, c_{24}^2}\left(1 - P^{(EARTH)}_{\nu_2 \to \nu_e}\right)$$

STATISTICAL ANALYSIS OF SOLAR NEUTRINO DATA

$$\chi^2 = \sum_{i,j} \left(R_i^{th} - R_i^{exp}\right) \left(V^{-1}\right)_{ij} \left(R_j^{th} - R_j^{exp}\right)$$

COVARIANCE MATRIX

THEORETICAL RATES:

$$R_i^{th} = \sum_{k=1}^{8} \phi_k \int dE_\nu \, \lambda_k(E_\nu) \Big[\sigma_{ei}(E_\nu) \langle P_{\nu_e \to \nu_e} \rangle + \sigma_{\mu i}(E_\nu) \left(1 - \langle P_{\nu_e \to \nu_e} \rangle - \langle P_{\nu_e \to \nu_s} \rangle\right) \Big]$$

ONLY K AND SK

Δm^2_{21}, θ_{12}, $c^2_{23} c^2_{24}$

WE USE LAST DATA FROM:

1) HOMESTAKE
2) GALLEX + SAGE
3) KAMIOKANDE
4) SUPER-KAMIOKANDE

PARAMETER ESTIMATION

$$\Delta m^2_{21}, \ \vartheta_{12}, \ c^2_{23} \ c^2_{24}$$

ESTIMATOR: χ^2_{min}

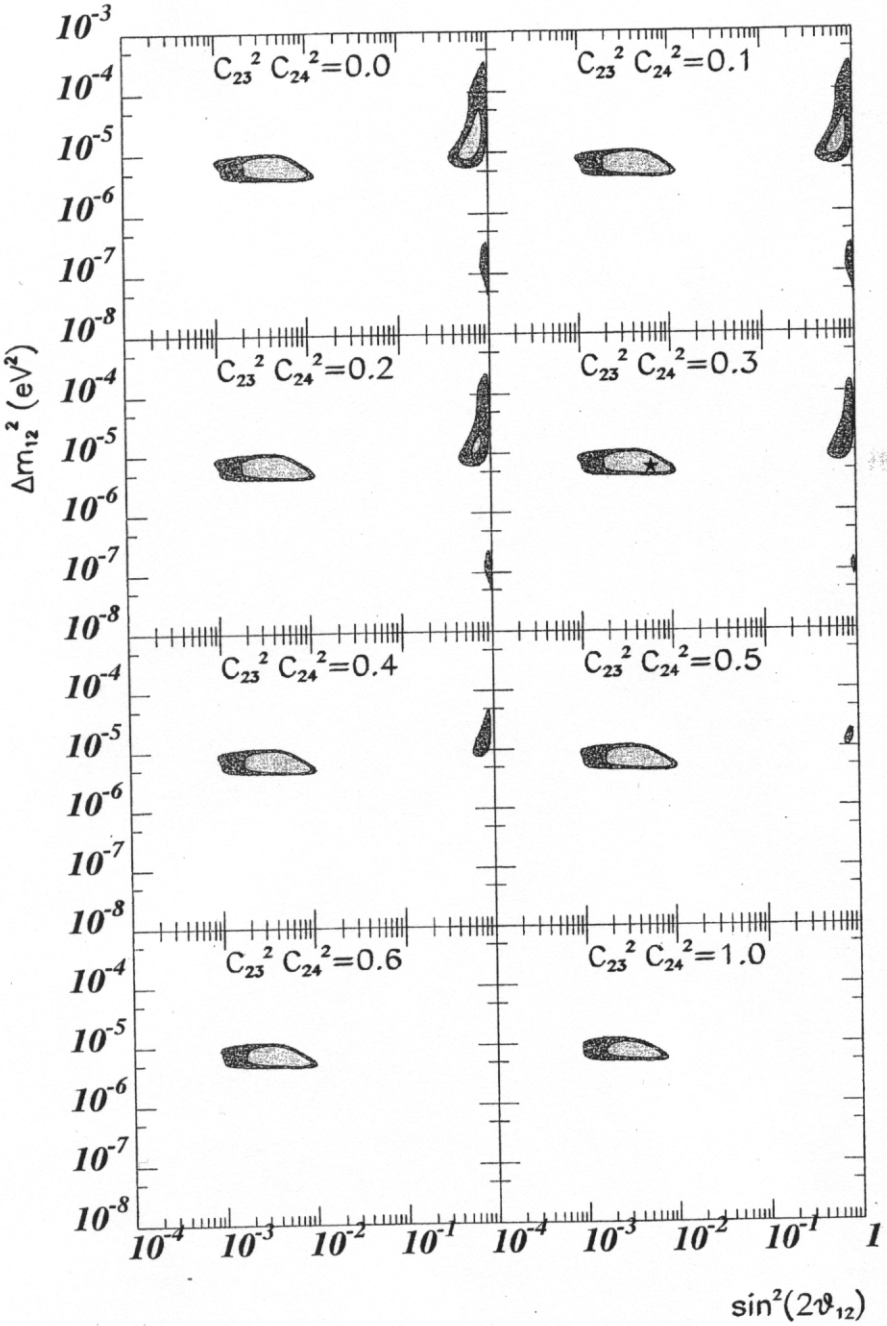
ALLOWED REGIONS:

$$\chi^2 < \chi^2_{min} + \Delta\chi^2(CL, 3_{DOF})$$

$CL = 90\% \longrightarrow \Delta\chi^2 = 6.25$

$CL = 95\% \longrightarrow \Delta\chi^2 = 7.83$

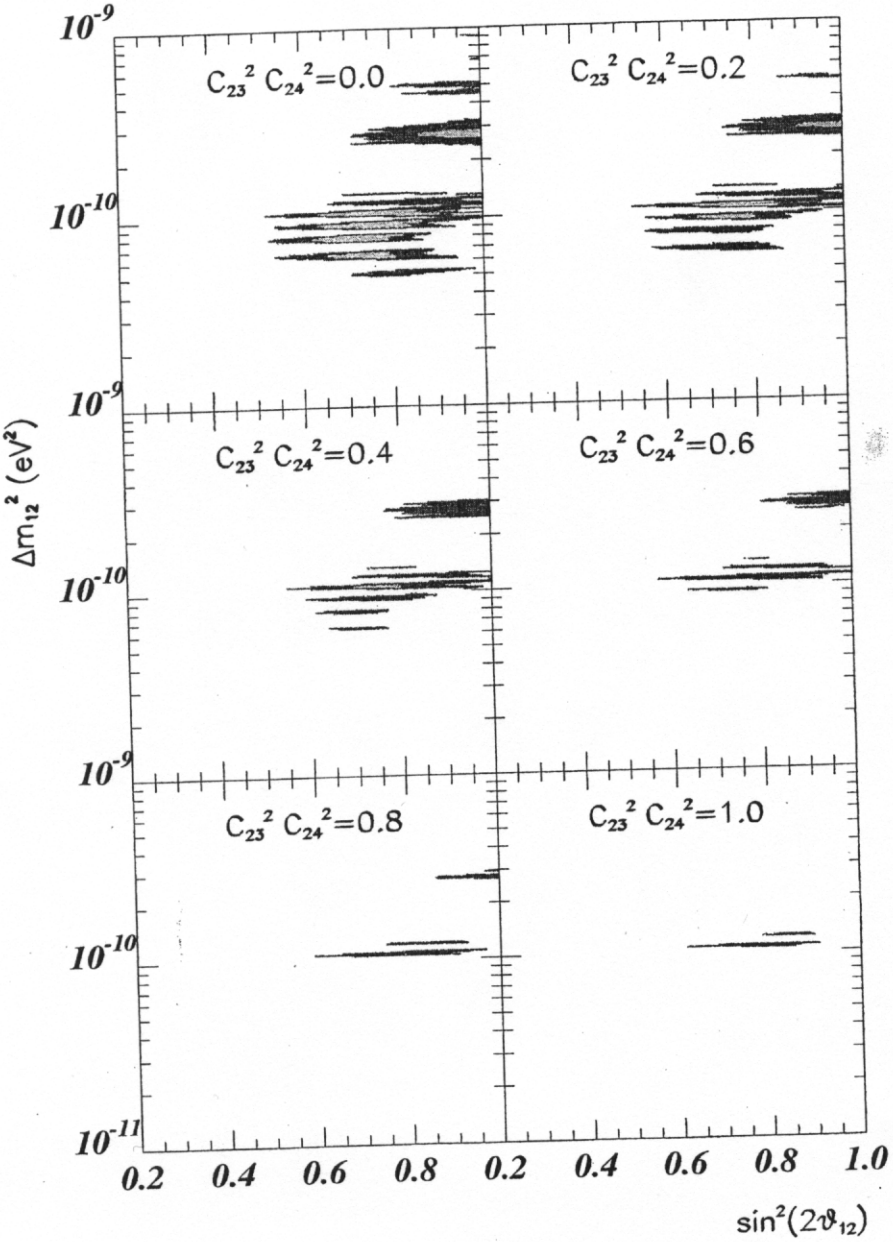
$CL = 99\% \longrightarrow \Delta\chi^2 = 11.36$



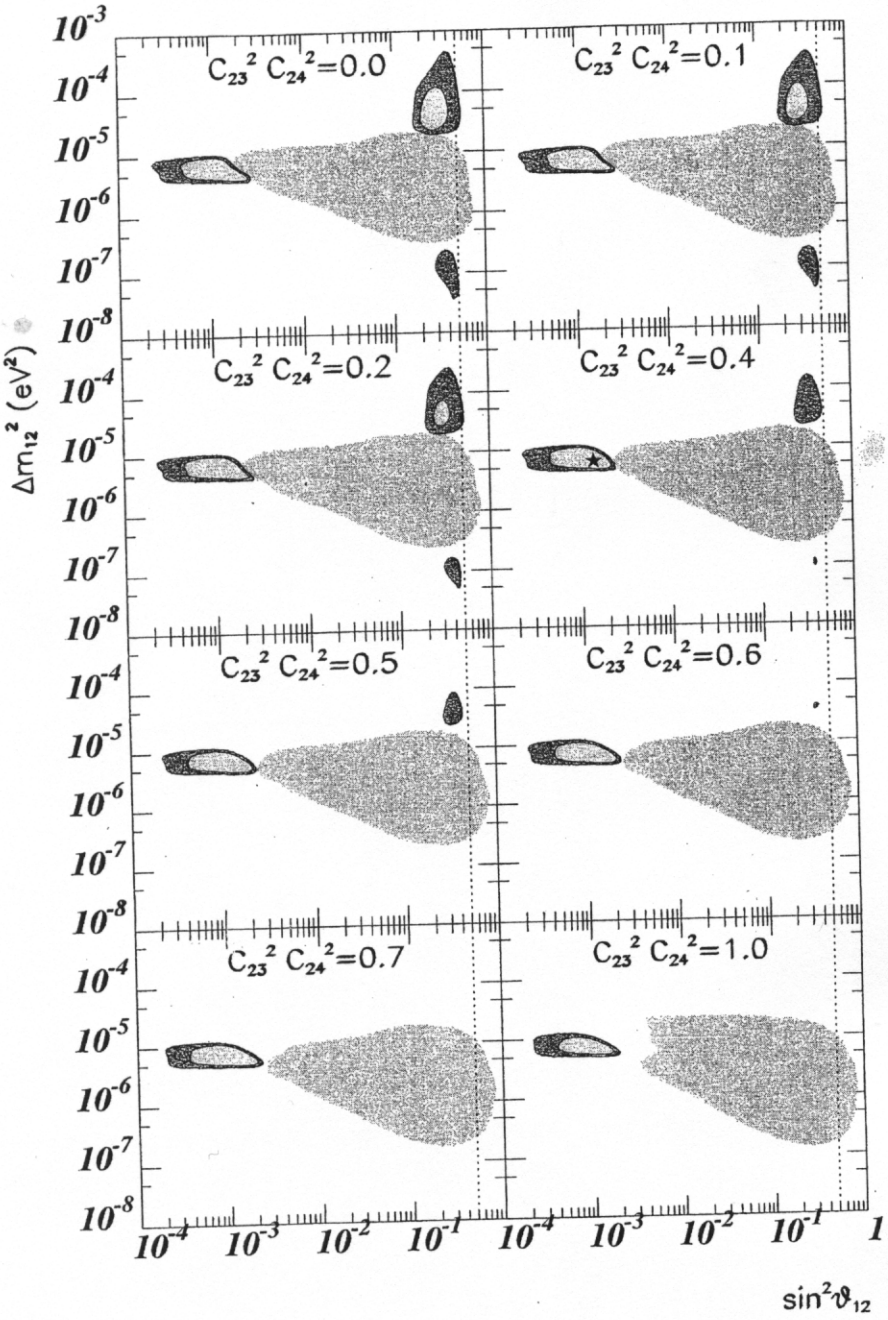
RATES ONLY

BEST FIT: SMA $C_{23}^2 C_{24}^2 = 0.3$

$\Delta m_{21}^2 = 5.6 \times 10^{-6}\, eV^2$ $\sin^2(2\vartheta_{12}) = 6.0 \times 10^{-3}$


$C_{23}^2\ C_{24}^2=0.0$
$C_{23}^2\ C_{24}^2=0.2$
$C_{23}^2\ C_{24}^2=0.4$
$C_{23}^2\ C_{24}^2=0.6$
$C_{23}^2\ C_{24}^2=0.8$
$C_{23}^2\ C_{24}^2=1.0$
10^{-9}
10^{-10}
10^{-11}
$\Delta m_{12}^2\ (eV^2)$
0.2
0.4
0.6
0.8
1.0
$\sin^2(2\vartheta_{12})$

RATES ONLY



RATES + ZENITH (SK)

BEST FIT: SMA $C_{23}^2 C_{24}^2 = 0.4$

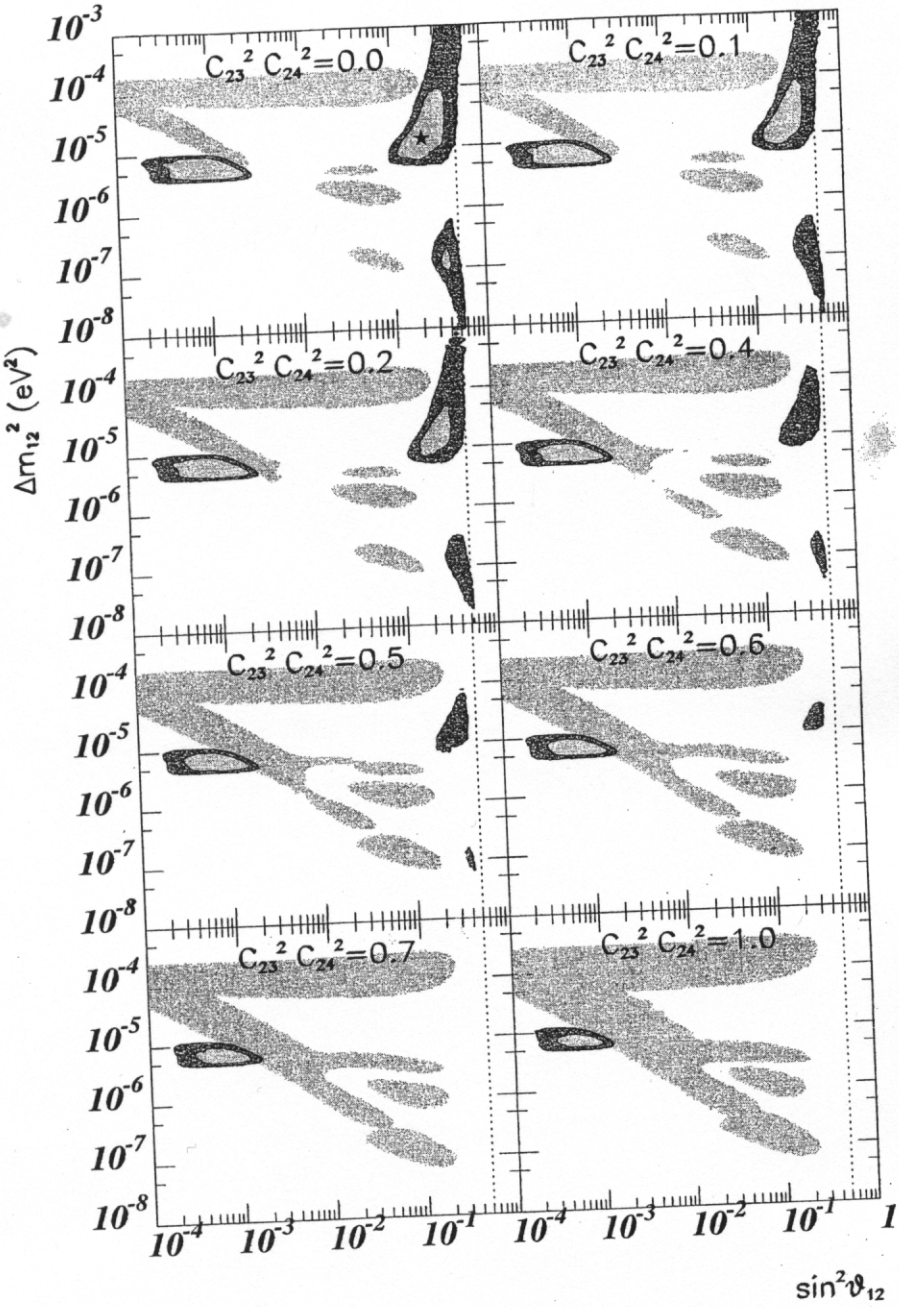
$\Delta m_{21}^2 = 6.2 \times 10^{-6}\ eV^2$ $\sin^2 2\vartheta_{12} = 5.4 \times 10^{-3}$

BEST FIT OF ZENITH ONLY: LMA $C_{23}^2 C_{24}^2 = 0$

$\Delta m_{21}^2 = 2.7 \times 10^{-6}\ eV^2$ $\sin^2\vartheta_{12} = 0.85$

$\vartheta_{12} > \pi/4$

RATES + SPECTRUM (SK)

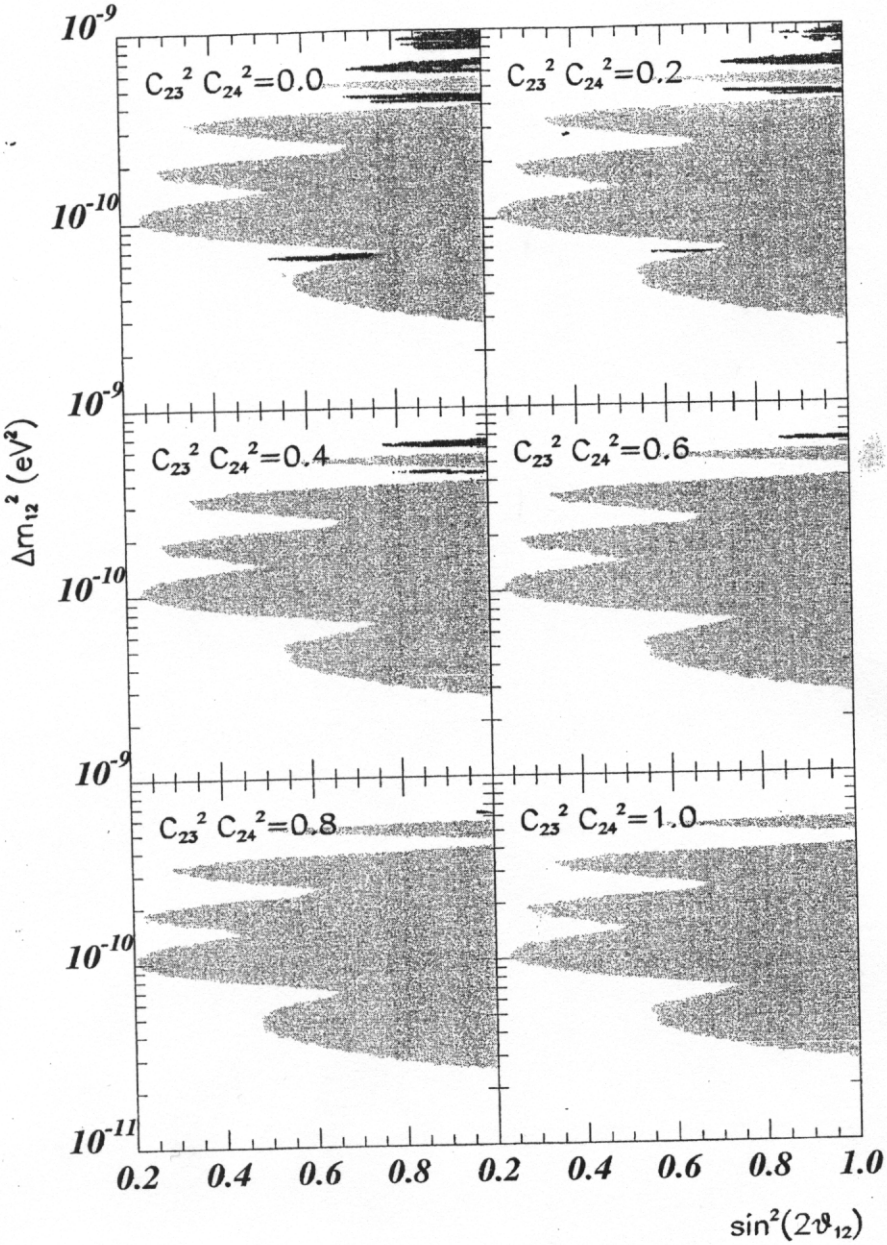


BEST FIT: LMA $C_{23}^2 C_{24}^2 = 0$

$\Delta m_{21}^2 = 1.4 \times 10^{-5} eV^2$ $\sin^2 2\vartheta_{12} = 0.68$

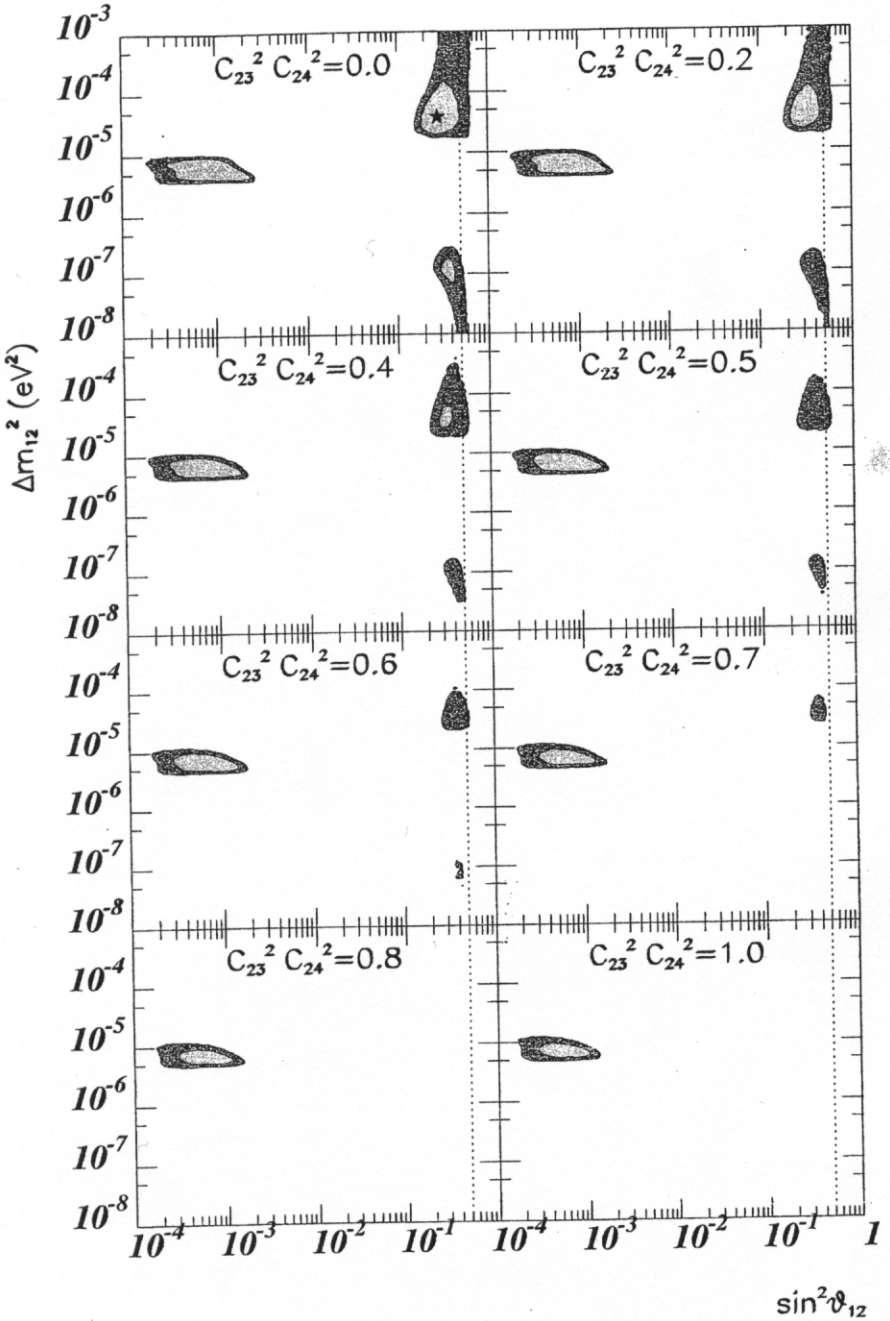
BEST FIT OF SPECTRUM ONLY: VO $C_{23}^2 C_{24}^2 = 0$

$\Delta m_{21}^2 = 6.3 \times 10^{-10} eV^2$ $\sin^2 2\vartheta_{12} = 1$



RATES + SPECTRUM (SK)

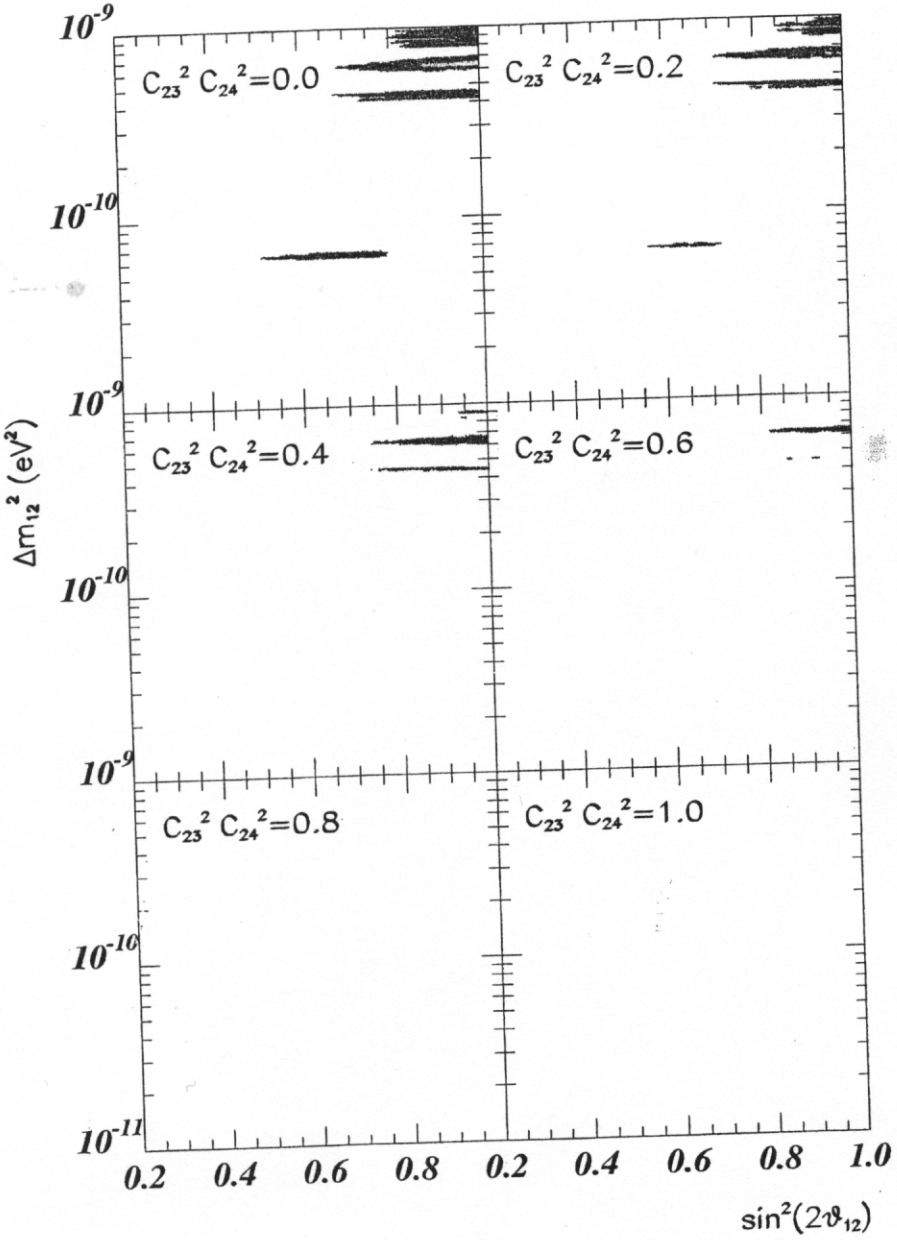
GLOBAL ANALYSIS

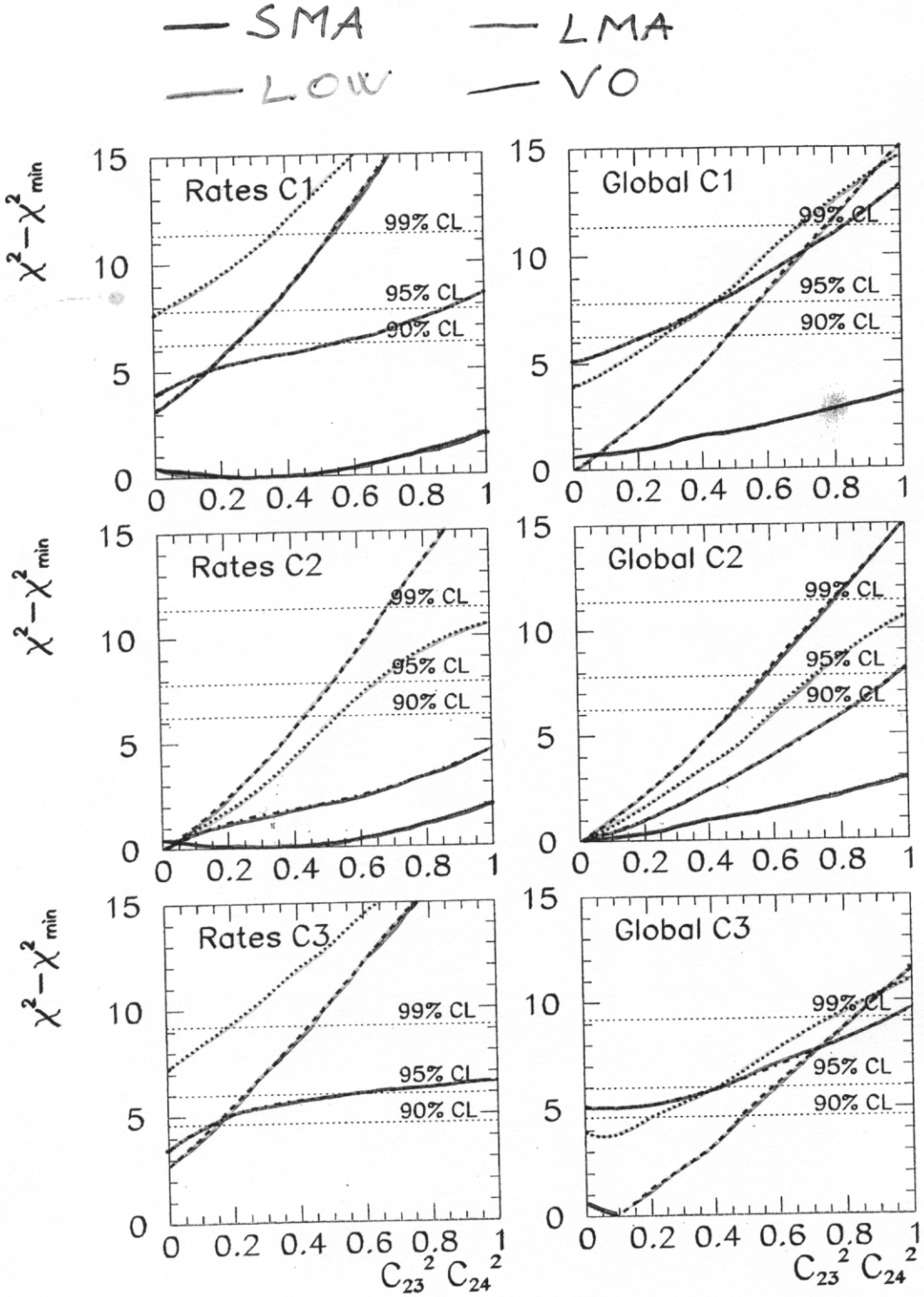


BEST FIT: LMA $\quad C_{23}^2 C_{24}^2 = 0$

$\Delta m_{21}^2 = 3.9 \times 10^{-5}\, eV^2 \quad \sin^2 2\vartheta_{12} = 0.78$

GLOBAL ANALYSIS




SMA
LMA
LOW
VO
Rates C1
Global C1
Rates C2
Global C2
Rates C3
Global C3
99% CL
95% CL
90% CL
$\chi^2-\chi^2_{min}$
$C_{23}^2\ C_{24}^2$
0
0.2
0.4
0.6
0.8
1
5
10
15

Experiment	Rate	Ref.	Units	R_i^{BP98}
Homestake	2.56 ± 0.23	[5]	SNU	7.8 ± 1.1
GALLEX + SAGE	72.3 ± 5.6	[6,7]	SNU	130 ± 7
Kamiokande	2.80 ± 0.38	[8]	10^6 cm^{-2} s^{-1}	5.2 ± 0.9
Super–Kamiokande	2.45 ± 0.08	[10]	10^6 cm^{-2} s^{-1}	5.2 ± 0.9

TABLE I. Measured rates for the Chlorine, Gallium, Kamiokande and Super–Kamiokande experiments.

		rates	rates+zenith	rates+spectrum	global
SMA	Δm^2	5.6×10^{-6}	6.2×10^{-6}	5.2×10^{-6}	5.2×10^{-6}
	$\sin^2(2\vartheta)$	6.0×10^{-3}	5.4×10^{-3}	4.7×10^{-3}	4.7×10^{-3}
	$c_{23}^2 c_{24}^2$	0.3	0.4	0.0	0.0
	χ^2_{min} (Prob %)	0.55 (45)	6.2 (40)	23.9 (16)	29.7 (16)
LMA	Δm^2	1.4×10^{-5}	4.2×10^{-5}	1.4×10^{-5}	3.9×10^{-5}
	$\sin^2(2\vartheta)$	0.68	0.81	0.68	0.78
	$c_{23}^2 c_{24}^2$	0.0	0.0	0.0	0.0
	χ^2_{min} (Prob %)	3.80 (5)	8.6 (20)	23.1 (19)	29.1 (18)
LOW	Δm^2	1.3×10^{-7}	1.1×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
	$\sin^2(2\vartheta)$	0.93	0.93	0.93	0.93
	$c_{23}^2 c_{24}^2$	0.0	0.0	0.0	0.0
	χ^2_{min} (Prob %)	8.3 (0.4)	13.6 (3.4)	27.9 (6.4)	33.0 (8.1)
Vacuum	Δm^2	9.1×10^{-10}	9.1×10^{-10}	4.5×10^{-10}	4.4×10^{-10}
	$\sin^2(2\vartheta)$	0.78	0.78	0.9	0.9
	$c_{23}^2 c_{24}^2$	0.0	0.0	0.0	0.0
	χ^2_{min} (Prob %)	4.5 (3.4)	9.9 (13)	28.8 (5.1)	34.3 (6.1)

TABLE II. Best fit points and the corresponding probabilities for the different solutions to the solar neutrino deficit and for different combinations of observables.

Observ.	Crit.	LMA 90 (99)	LOW 90 (99)	VAC 90 (99)
Rates	C1	0.25 (0.54)	– (0.36)	0.56 (1.0)
	C2	0.44 (0.69)	0.54 (1.00)	1.0 (1.0)
	C3	0.14 (0.43)	– (0.18)	0.12 (1.0)
Rates+SK Zenith	C1	0.30 (0.61)	– (0.45)	0.61 (1.0)
	C2	0.45 (0.74)	0.59 (0.90)	1.0 (1.0)
	C3	0.19 (0.49)	– (0.23)	0.15 (1.0)
Rates+SK Spect	C1	0.43 (0.67)	0.18 (0.56)	0.12 (0.77)
	C2	0.43 (0.67)	0.54 (1.0)	0.83 (1.0)
	C3	0.45 (0.72)	– (0.57)	– (0.93)
Global fit	C1	0.48 (0.78)	0.28 (0.70)	0.22 (0.83)
	C2	0.48 (0.78)	0.61 (1.0)	0.83 (1.0)
	C3	0.48 (0.83)	0.20 (0.76)	– (0.95)

TABLE III. Maximum allowed value of $\cos^2_{23}\cos^2_{24}$ at 90 % and 99 % CL for the different solutions to the solar neutrino problem with the different statistical criteria. SMA is allowed at 90 % for all the range of $\cos^2_{23}\cos^2_{24}$.

CONCLUSIONS

- TWO ALLOWED 4-ν SCHEMES:

(A) $\overbrace{\underbrace{m_1 < m_2}_{\text{ATM}} < \underbrace{m_3 < m_4}_{\text{SUN}}}^{\text{LSND}}$

$\overbrace{\underbrace{m_1 < m_2}_{\text{SUN}} < \underbrace{m_3 < m_4}_{\text{ATM}}}^{\text{LSND}}$ (B)

- THE TWO SCHEMES ARE EQUIVALENT FOR OSCILLATION EXPERIMENTS

- SOLAR ν OSCILLATIONS DEPEND ON 3 PARAMETERS:

$$\Delta m^2_{21}, \quad \vartheta_{12}, \quad C^2_{23} C^2_{24} \qquad \text{(B)}$$

- THE **SMA** REGION IS A VALID SOLUTION FOR ALL VALUES OF $C^2_{23} C^2_{24}$

- THE **LMA**, **LOW**, **VO** SOLUTIONS DISAPPEAR FOR LARGE VALUES OF $C^2_{23} C^2_{24}$ (DOMINANT $\nu_e \to \nu_s$ TRANSITIONS)

- HOPEFULLY FUTURE DATA (SNO, BOREXINO, ...) WILL INDICATE A SPECIFIC REGION AND WILL ALLOW TO CONSTRAINT $C_{23}^2 C_{24}^2$
- MOST INTERESTING POSSIBILITY : $C_{23}^2 C_{24}^2$ CONSTRAINED TO BE $\neq 0$ AND $\neq 1$

  PLAUSIBLE SCENARIO : SMALL $C_{23}^2 C_{24}^2$

  SUN : DOMINANT $\nu_e \to \nu_s$, SUBDOMINANT $\nu_e \to \nu_{\mu,\tau}$

  ATM : DOMINANT $\nu_\mu \to \nu_\tau$, SUBDOMINANT $\nu_\mu \to \nu_s$
- EVENTUALLY A GLOBAL ANALYSIS OF ALL DATA WILL BE NECESSARY (SOLAR, ATMOSPHERIC, SBL, LBL, νFACT) + (SUPERNOVA, EARLY UNIVERSE)
- MORE SURPRISES ? (DATA CANNOT BE FITTED WITH 4 ν's)