4-25-03
ARGONNE
OFFAXIS DETECTOR WORKSHOP

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NEXT-GENERATION NEUTRINO OSCILLATION EXPERIMENTS: WHAT TO AIM AT, AND WHY.

- THE SM LEPTONIC SECTOR IN 2003
- 3 FLAVOR OSCILLATIONS
  - PARAMETERS
  - WHAT WE KNOW
  - WHAT WE NEED TO FIND OUT: $|U_{e3}|$ ET AL.
- WHY DO WE CARE ABOUT U_{e3}?
  - THEORETICAL PREJUDICES
  - CP-VIOLATION + LEPTOGENESIS
- SUMMARY

THE LEPTONIC SECTOR IN 1998

CHARGED LEPTONS:

$e, \mu, \tau \Rightarrow$ VERY, VERY WELL KNOWN

(MASSES, CHARGES, DECAY WIDTHS, ETC)

NEUTRAL LEPTONS

$\nu_e, \nu_\mu \rightarrow$ DIRECTLY DETECTED

$\nu_\tau \rightarrow$ INDIRECTLY INFERRED

$\oplus \begin{cases} N_\nu^{\text{ACTIVE}} = 2.994 \pm 0.012 \\ N_\nu^{\text{ACTIVE}} = 3.07 \pm 0.12 \end{cases}$ $\boxed{\text{bRI}}$

$$\left.\begin{array}{l} m_{\nu_e} < 15 \text{ eV} \\ m_{\nu_\mu} < 170 \text{ keV} \\ m_{\nu_\tau} < 18 \text{ MeV} \end{array}\right\} \text{1998 PDG}$$

$\oplus$ (COSMOLOGY) $\sum m_\nu < 24 \text{eV}$ OR $m_\nu > 1 \text{ MeV}$

"IF THE NEUTRINOS HAVE MASS"

LEPTON MIXING

SOLAR PUZZLE: PREFERRED SMALL MIXING ANGLE

ATMOSPHERIC PUZZLE: NOT WELL-ESTABLISHED/TRUSTED

LSND ANOMALY: " "

NATURE OF THE NEUTRINO: MAJORANA × DIRAC

$m_{\beta\beta} <$ FEW eV [ν-LESS DOUBLE BETA DECAY]

THE (NEUTRAL) LEPTONIC SECTOR IN 2003

NEUTRINO PUZZLES → EVIDENCE FOR OSCILLATION

→ $\boxed{\text{NEUTRINO MASSES + MIXING}}$

- ν_τ OBSERVED DIRECTLY
- $\sum m_\nu < 0.7\,eV$ → WMAP [HANDLE WITH CARE!]
- $|U_{e1}|^2 m_1^2 + |U_{e2}|^2 m_2^2 + |U_{e3}|^2 m_3^2 < (2.2\,eV)^2$ → TRITIUM β-DECAY

ON THE OTHER HAND...

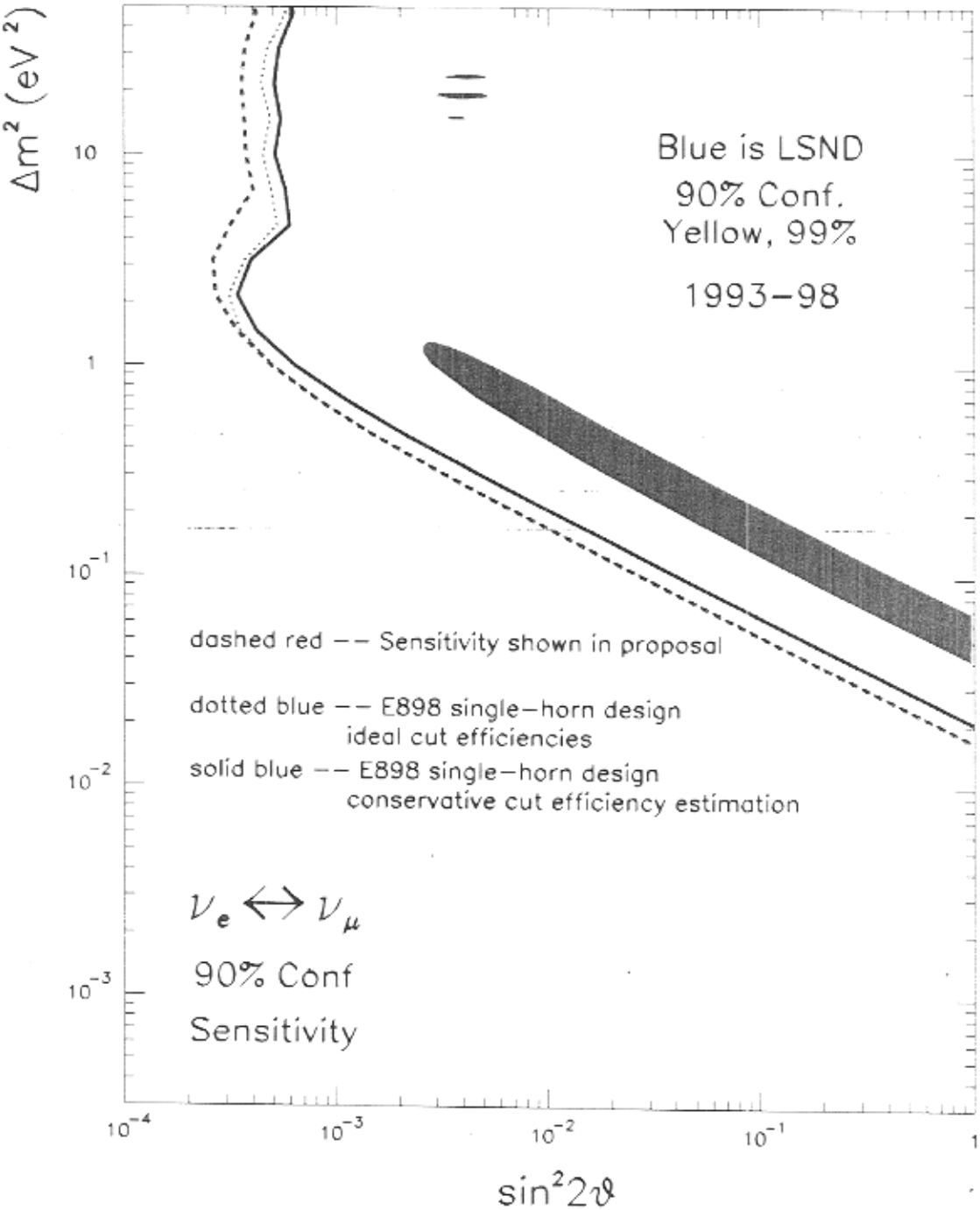
LSND ANOMALY STILL NOT WELL-ESTABLISHED / TRUSTED

- WAITING FOR MINIBOONE

NATURE OF THE NEUTRINO: MAJORANA × DIRAC

$m_{\beta\beta} < 0.35\,eV$ (OR SEEN?)

SENSITIVITY OF THE MINI BOONE EXPERIMENT



START OF DATA TAKING → END OF JUNE 2002 :

WHAT HAVE WE LEARNED?

- WE NOW KNOW THAT NEUTRINOS CHANGE FLAVOR AFTER PROPAGATING LONG DISTANCES

WE ARE VERY SURE ABOUT THESE !

- SOLAR ν_e's CONVERT (PARTIALLY) INTO ν_μ's AND/OR ν_τ's ON THEIR WAY TO THE EARTH [SUPERK, SNO]

- ATMOSPHERIC ν_μ's CONVERT (PARTIALLY) INTO ν_τ's ON THEIR WAY TO UNDERGROUND DETECTORS. THE LONGER THEY TRAVEL, THE MORE THEY CONVERT [SUPERKAMIOKANDE]

- REACTOR $\bar{\nu}_e$'s "DISAPPEAR" AFTER PROPATING AT LEAST SEVERAL TENS OF KILOMETERS [KAMLAND]

T.B.C. MINIBOONE

- $\bar{\nu}_\mu$'s TURN [A LITTLE] INTO $\bar{\nu}_e$'s AFTER $\mathcal{O}(30\,m)$ OF PROPAGATION IN THE LSND EXPERIMENT.

ALL NEUTRINO "ANOMALIES" ARE SOLVED BY ASSUMING THAT NEUTRINOS HAVE MASS AND THAT FLAVOR EIGENSTATES DIFFER FROM MASS EIGENSTATES.

FOR 2 GENERATIONS PROPAGATING <u>IN VACCUM</u>

$$P(\nu_\alpha \to \nu_\beta) \equiv P_{\alpha\beta} = \operatorname{sen}^2 2\theta \, \operatorname{sen}^2 \left[\frac{\Delta m^2 L}{4E} \right]$$

NEW PHYSICAL PARAMETERS

Δm^2 = MASS-SQUARED DIFFERENCE $(m_2^2 - m_1^2)$ OF NEUTRINO MASS EIGENSTATES.

θ = MIXING ANGLE $\begin{pmatrix} \nu_\alpha \\ \nu_\beta \end{pmatrix} = \begin{pmatrix} \cos\theta & \operatorname{sen}\theta \\ -\operatorname{sen}\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$

"EXPERIMENTAL" PARAMETERS

L = DISTANCE TRAVELED

E = NEUTRINO ENERGY

THE MINIMALLY EXTENDED S.M.

- MOST "BORING" SCENARIO
  - LSND WILL "GO AWAY" AFTER MINI-BOONE
  - OSCILLATIONS WILL BE FIRMLY ESTABLISHED [MINOS, CNGS, KAMLAND, BOREXIN

$\Rightarrow$ WE NEED TO SOLVE ATMOSPHERIC + SOLAR PUZZLES WITH MASS-INDUCE OSCILLATIONS (+ CHOOZ)

3 FLAVORS

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$(\text{MASSES})^2 = m_1^2, m_2^2, m_3^2$

$\Downarrow$

3 MIXING ANGLES

1 (OBSERVABLE) CP-ODD PHASE

- FIT FOR MIXING ANGLES + Δm^2_{ij}

PARAMETERIZING 3ν OSCILLATIONS

1- DEFINE MASS EIGENSTATES

$$0 < \Delta m^2_{12} < |\Delta m^2_{13}|, |\Delta m^2_{23}|$$

2- WITHIN THIS DEFINITION + GIVEN THE CURRENT DATA

- $tg^2\theta_{SOL} = tg^2\theta_{12} \equiv \dfrac{|U_{e2}|^2}{|U_{e1}|^2}$ • $\Delta m^2_{SOL} = \Delta m^2_{12}$

- $tg^2\theta_{ATM} = tg^2\theta_{23} = \dfrac{|U_{\mu 3}|^2}{|U_{23}|^2}$ • $|\Delta m^2_{13}| \sim |\Delta m^2_{23}| = \Delta m^2_{ATM}$

- $\operatorname{sen}^2\theta_{13} = |U_{e3}|^2$ → CONSTRAINED BY CHOOZ

- CP-ODD PHASE

$$\left\{ J = \operatorname{Im}\left[U^*_{e3} U_{\mu 3} U_{e2} U^*_{\mu 2} \right] = \frac{1}{8} \sin 2\theta_{23} \sin 2\theta_{12} \sin 2\theta_{13} \cos\theta_{13} \times \right.$$

$$\times \underline{\operatorname{sen}\delta}$$

FINAL CHOOZ RESULT

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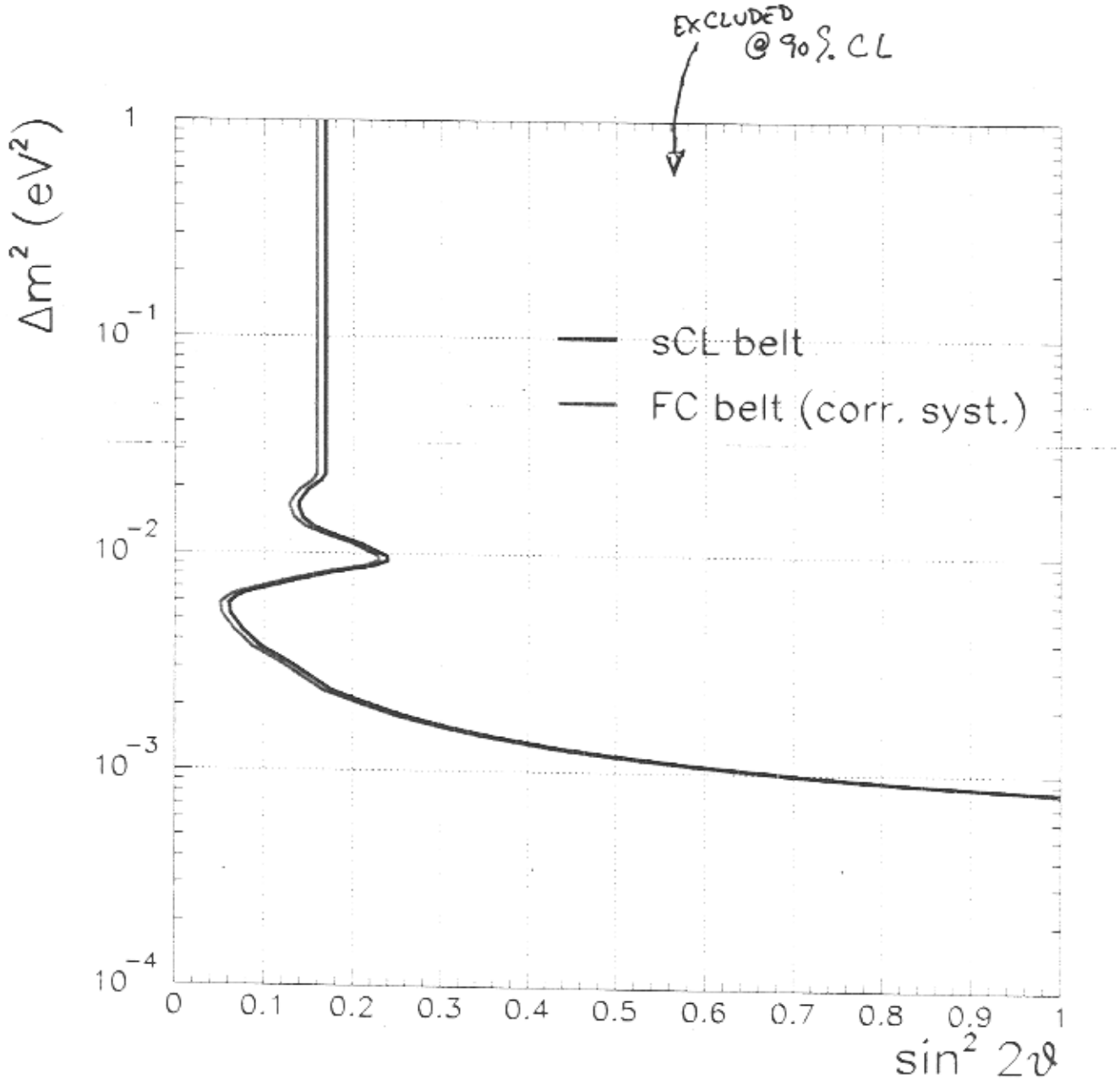

LISI ETAL

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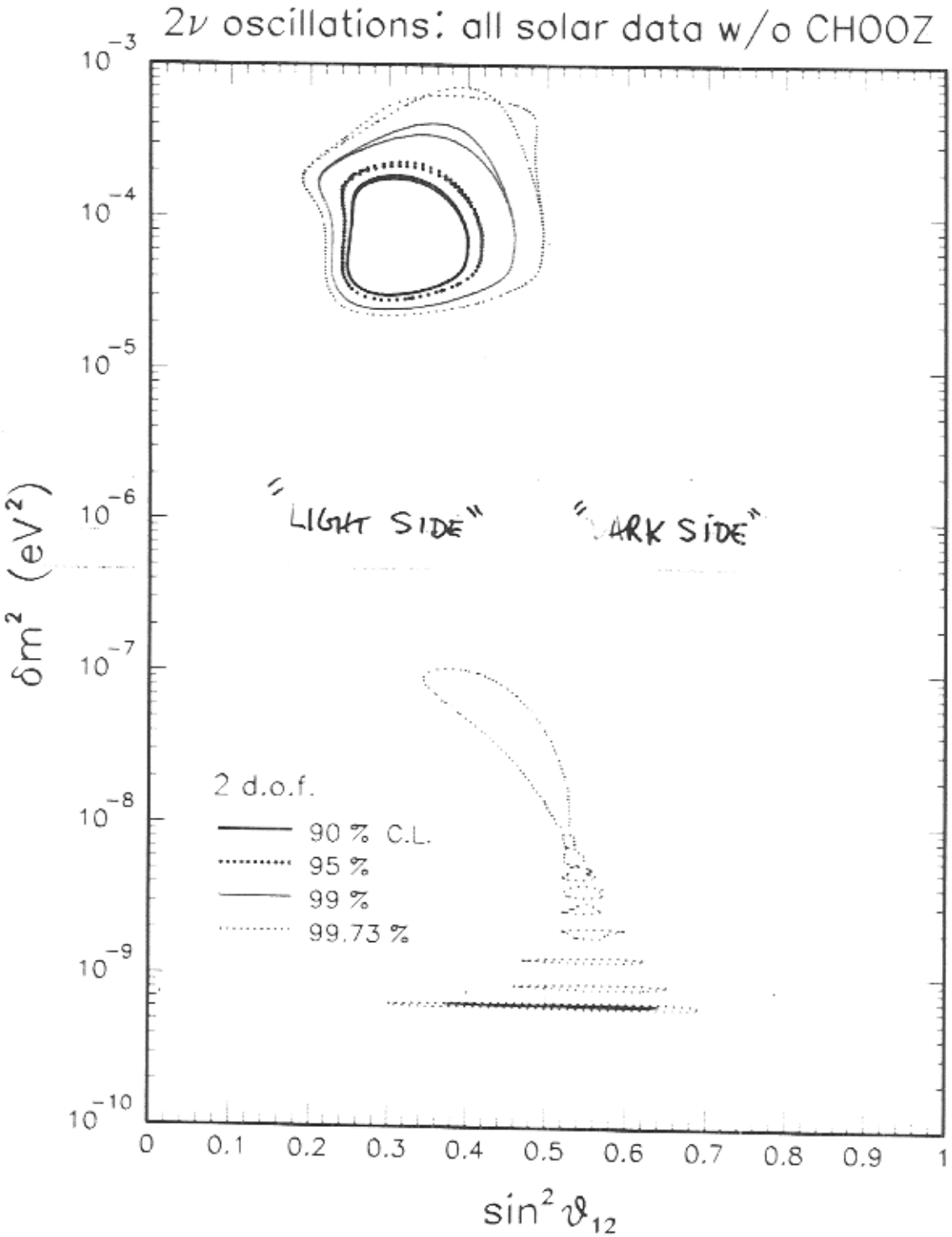
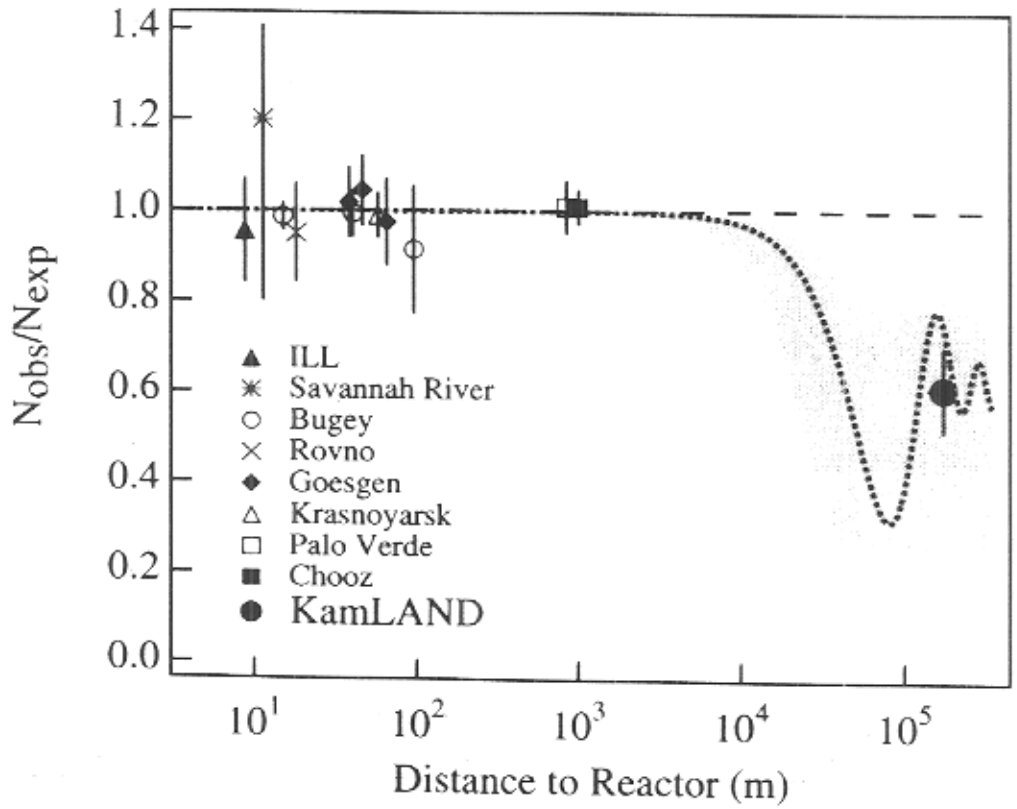
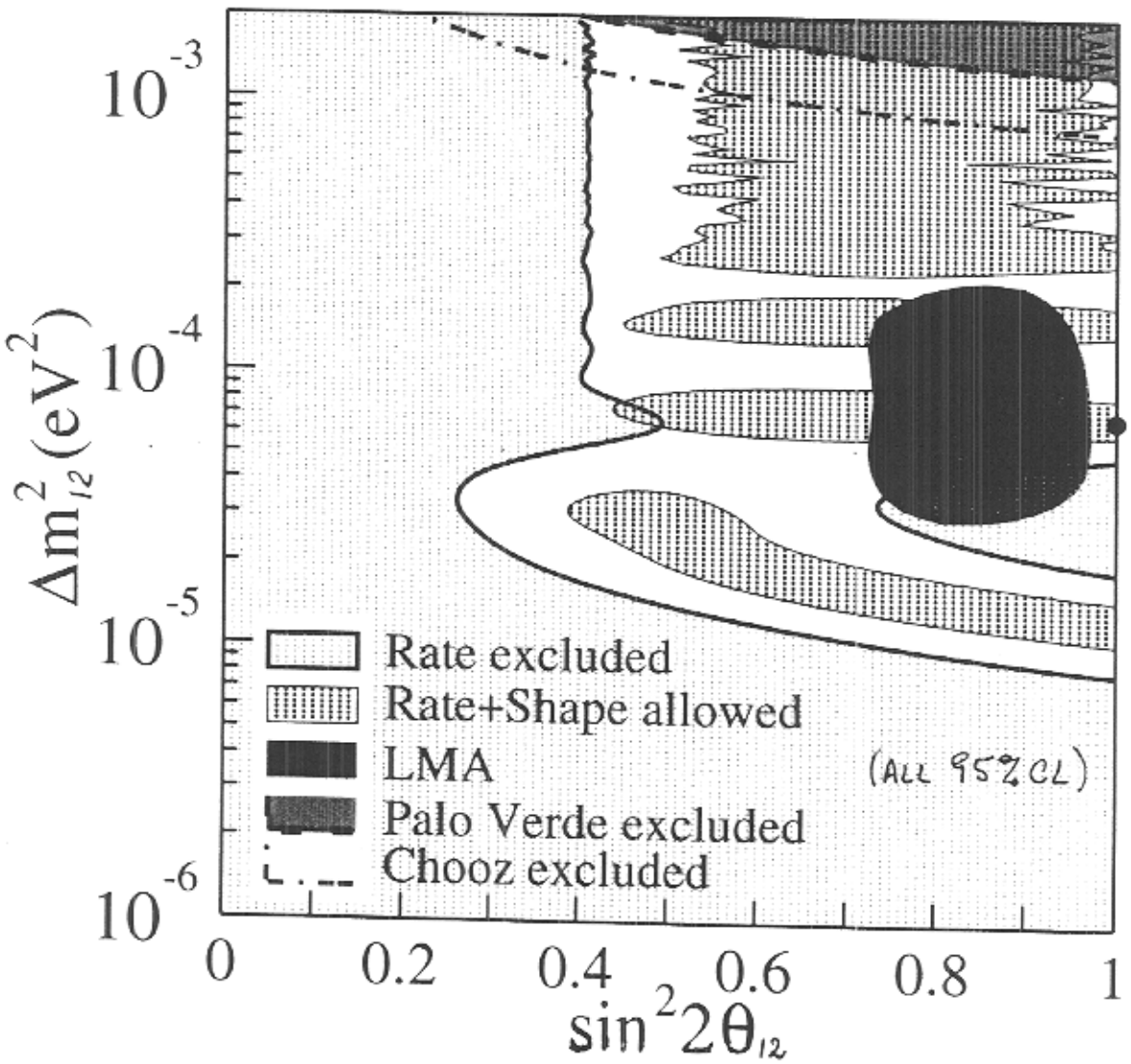
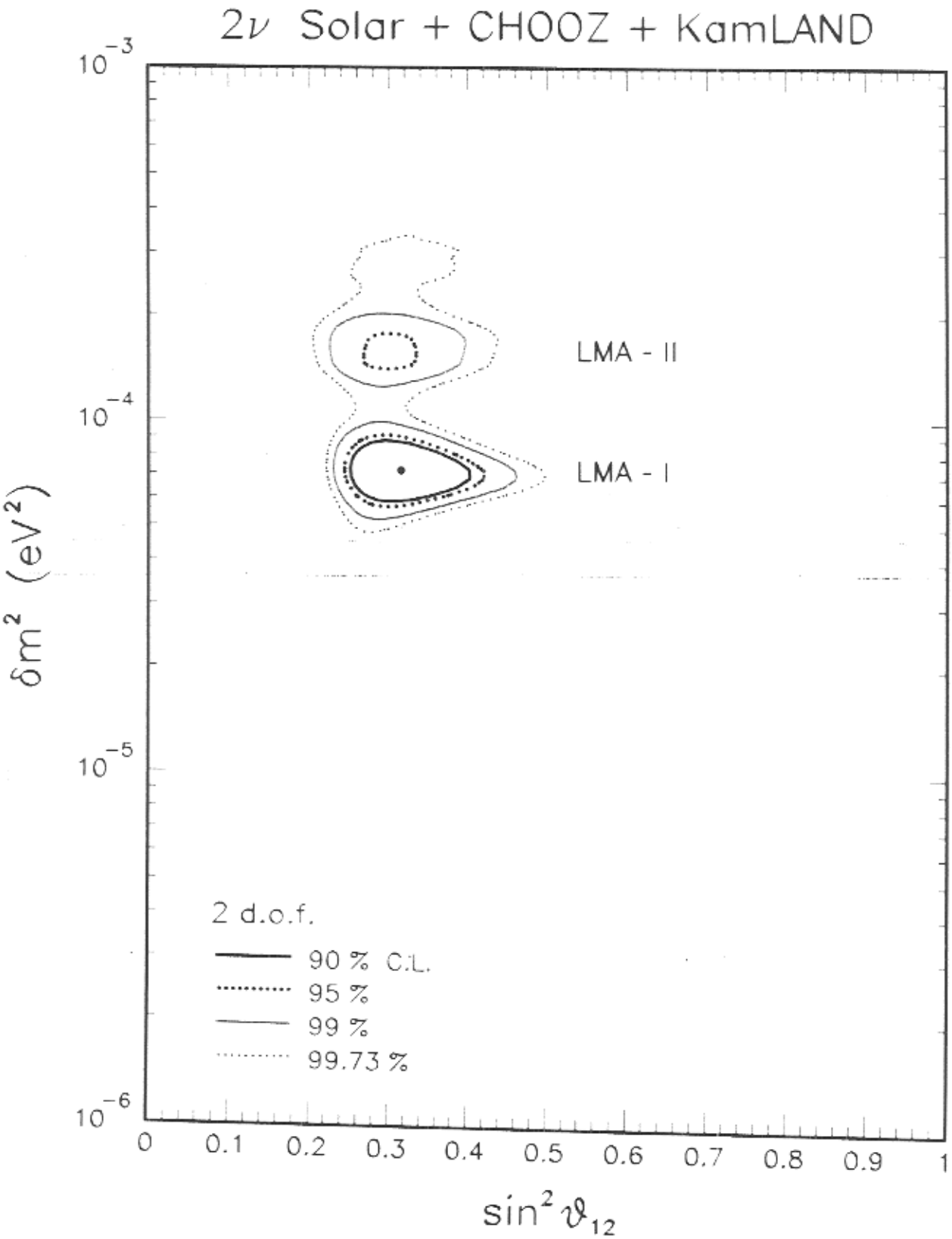


FIG. 1: Two-flavor global analysis of solar neutrino oscillations in the $(\delta m^2, \sin^2\theta_{12})$ parameter space, with and without the additional constraints placed by the CHOOZ reactor experiment. The inclusion of CHOOZ leads to slightly more restrictive upper bounds on δm^2.

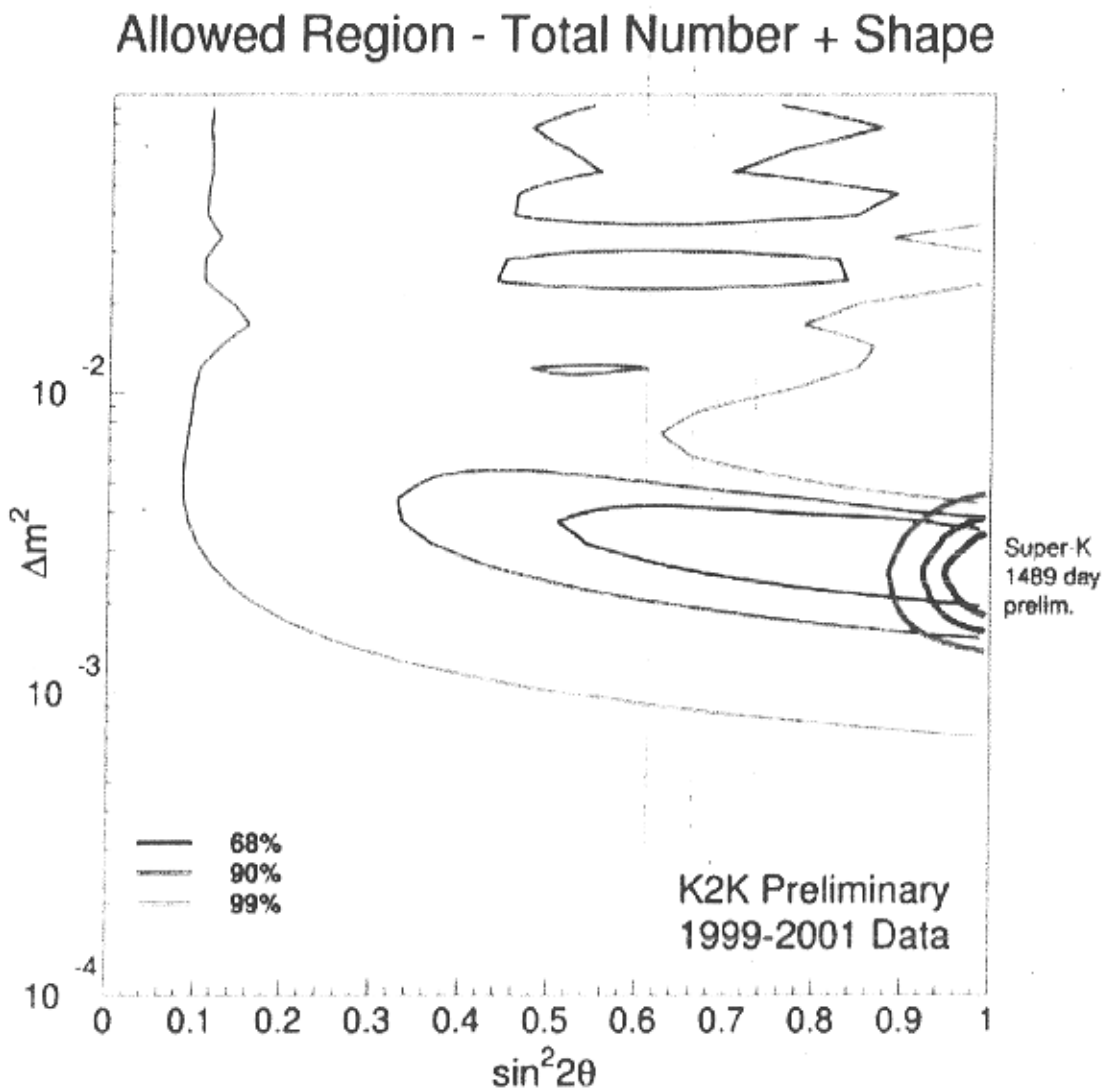

1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
N_{obs}/N_{exp}
ILL
Savannah River
Bugey
Rovno
Goesgen
Krasnoyarsk
Palo Verde
Chooz
KamLAND
10^1
10^2
10^3
10^4
10^5
Distance to Reactor (m)


10^{-3}
10^{-4}
10^{-5}
10^{-6}
$\Delta m^2_{12}(eV^2)$
Rate excluded
Rate+Shape allowed
LMA
Palo Verde excluded
Chooz excluded
(ALL 95% CL)
0
0.2
0.4
0.6
0.8
1
$\sin^2 2\theta_{12}$



FOGLI ET AL IN HEP-PH/0212127

Comparison with SK atm ν observation



$\nu_\mu \leftrightarrow \nu_\tau$

OSCILLATIONS

+ MEASURING WITH
APPROVED
EXPERIMENTS

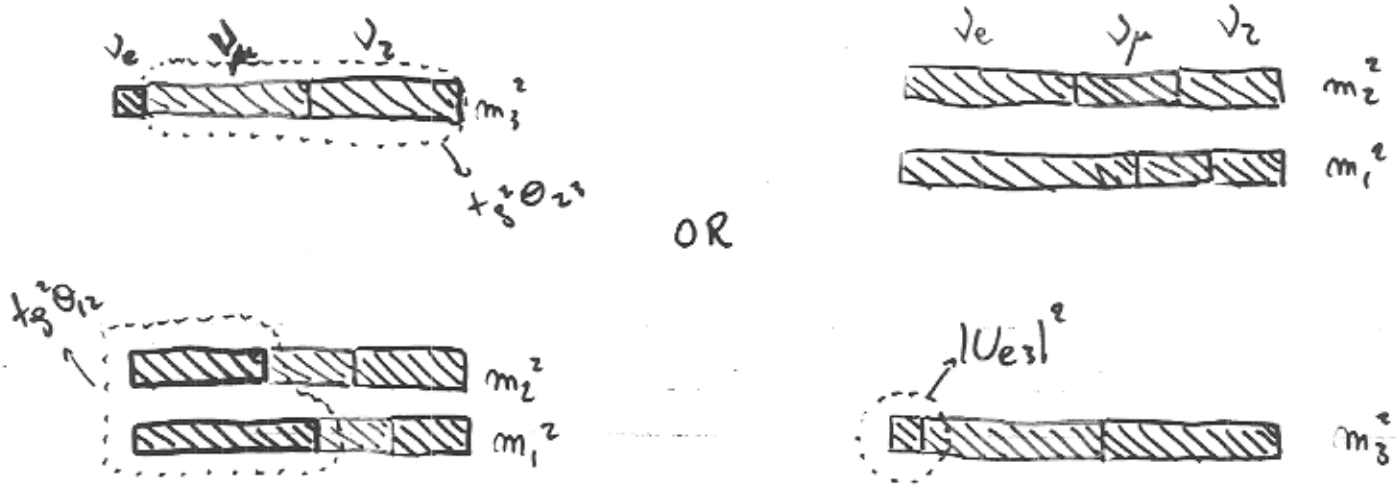
WE WILL MEASURE "VERY WELL" { KAMLAND [LMA]
BOREXINO [LOW KAC] EXCLUDED?

WE WILL MEASURE VERY WELL (~10%) { MINOS
CNGS

NO HOPE TO IMPROVE SIGNIFICANTLY THE CHOOZ BOUND (?)

OF COURSE, NO HOPE

WHAT IS LEFT?



$\Delta m^2_{13} > 0$ $\Delta m^2_{13} < 0$

1 - $|U_{e3}|^2$

2 - WHAT IS THE MASS HIERARCHY?

3 - WHAT IS THE CP-ODD PHASE?

[2] CAN BE ADDRESSED WITHIN OSCILLATIONS IF $|U_{e3}|^2$ is BIG

[3] CAN BE ADDRESSED WITHIN OSCILLATIONS IF LMA + $|U_{e3}|^2$ BIG

LOOKING FOR $|U_{e3}|^2$ EFFECTS: $\nu_\mu \to \nu_e$ TRANSITIONS

WHY?

- IT IS "EASY" TO PRODUCE A ν_μ BEAM $[\pi \to \mu \nu_\mu]$ OF "HIGH ENOUGH" ENERGY
- APPEARANCE IS THE "RIGHT WAY" TO REACH VERY SMALL ANGLES (FOR DISCOVERY ANYWAY)... [X DISAPPEARANCE]
- SUCH A SETUP WILL PROVIDE (REQUIRED) PRECISE INFORMATION ON THE ATMOSPHERIC PARAMETERS.

$$P^{VAC}_{\bar{\mu}\bar{e}} = 4\,|U_{\mu 3}|^2 |U_{e3}|^2 \sin^2 \Delta_{13} -$$

OPTIMIZE $\Delta_{13} \to \pi/2$

$$-4\,\mathrm{Re}[U_{\mu 1} U^*_{e1} U^*_{\mu 2} U_{e2}] \sin^2 \Delta_{12} \dashrightarrow \Delta^2_{12} \text{ SUPP}$$

$$+2\,\mathrm{Re}[U_{\mu 2} U^*_{e2} U^*_{\mu 3} U_{e3}] \left[\cos 2(\Delta_{12} - \Delta_{13}) - \cos 2\Delta_{13}\right]$$

$$\mp 8\,\mathrm{Im}[U_{\mu 2} U^*_{e2} U^*_{\mu 3} U_{e3}] \sin \Delta_{12} \sin \Delta_{13} \sin(\Delta_{13} - \Delta_{12})$$

$|U_{e3}| \times \Delta_{12}$

CP-ODD

$$\boxed{\Delta_{ij} \equiv \Delta m^2_{ij} \frac{L}{4E}}$$

MATTER EFFECTS MATTER!

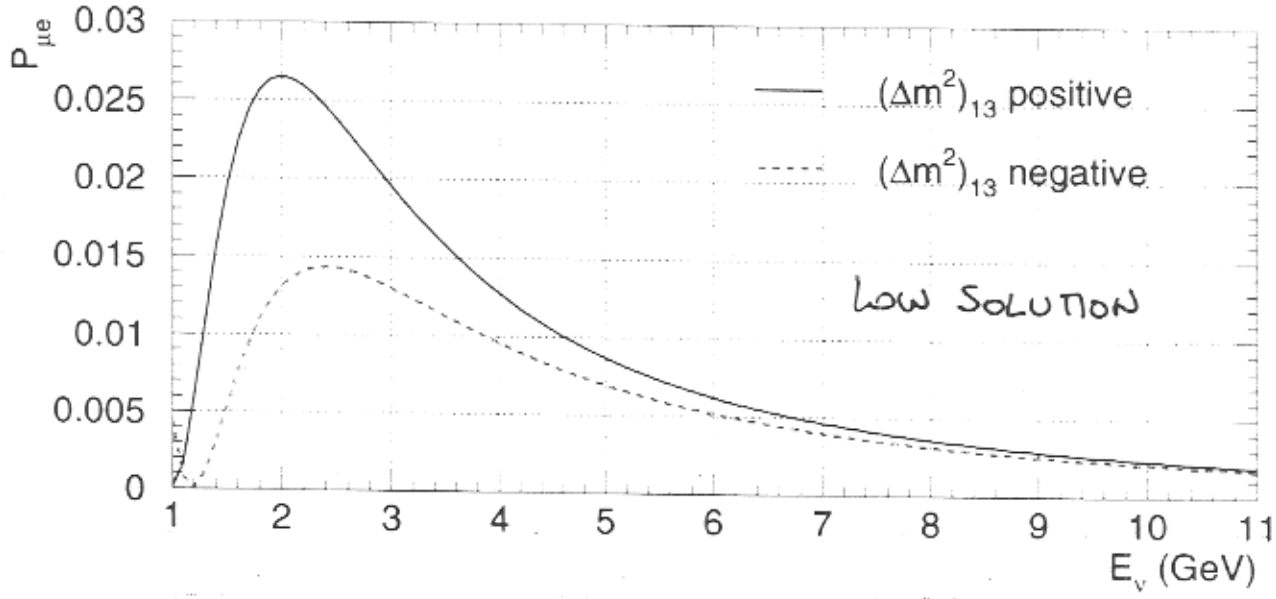


Figure 1: $\bar{\nu}_\mu \to \nu_e$ oscillation probability for $\Delta m^2_{13} > 0$ (solid line) and $\Delta m^2_{13} < 0$ (dashed line). $|\Delta m^2_{13}| = 3 \cdot 10^{-3}$ eV^2, $\theta_{\rm atm} = \pi/4$, $\Delta m^2_{\odot} = 1 \times 10^{-7}$ eV^2, $\theta_{\odot} = \pi/6$, $|U_{e3}|^2 = 0.01$, and $\delta = 0$. L = 900 km

[BARENBOIM, ADG, ZLEPER, VELASCO, HEP-PH/0204208]

$$\frac{\Delta m^2}{2E} \times \sqrt{2}\, G_F N_e \approx 1.4 \times 10^{-4} \frac{eV^2}{GeV}$$

AS LONG AS $E \lesssim 10$ GeV, MATTER EFFECTS ARE AN IMPORTANT PERTURBATION. NOTE THAT FOR $E > 10$ GeV, WE NEED DISTANCES BIGGER THAN $\gtrsim 5000$ km TO ATN AT $\Delta_{13} \sim \pi/2$ ...

WHY DO CARE ABOUT MEASURING $|U_{ei}|$ ET AL?

- NEUTRINO MIXING PARAMETERS ARE FUNDAMENTAL CONSTANTS OF THE (NOW EXTENDED) STANDARD MODEL, LIKE THE CABIBBO ANGLE, THE FINE STRUCTURE CONSTANT OR THE W-BOSON MASS

- WE HAVE THE OPPORTUNITY TO PROBE WHETHER CP-INVARIANCE HOLDS IN THE LEPTONIC SECTOR. FURTHERMORE, WE CAN CHECK WHETHER THE "CKM-LIKE" PICTURE WE HAVE DRAWN (3 FLAVOR MIXING) IS REALLY CORRECT, OR WHETHER EXTRA INGREDIENTS ARE REQUIRED.

- PRECISE MEASUREMENTS OF THE NEUTRINO MIXING PARAMETERS WILL CERTAINLY SHED MORE LIGHT INTO OUR UNDERSTANDING OF THE PHYSICS BEYOND THE S.M. AND THE MYSTERIES OF FLAVOR.

THEORETICAL PREJUDICES: WHAT IS THE EXPECTED VALUE OF $|U_{e3}|$?

ANSWER: WE SIMPLY DO NOT KNOW!

REMEMBER: THE FIRST, NAIVE GUESS FOR THE VALUE OF THE NEUTRINO PARAMETERS [V_{LEPTON} & V_{CKM}] WAS JUST WRONG.

$$V_{CKM} \approx \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} \quad \text{VERSUS} \quad V_{LEPTON} \approx \begin{pmatrix} 1 & 1 & U_{e3} \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$|U_{e3}| \lesssim 0.2$$

$$\lambda = \operatorname{sen}\theta_c = 0.22$$

THE FACT THAT WE DON'T KNOW THE "PHYSICS" BEHIND MASSES + MIXING DOES NOT STOP US FROM TRYING – QUITE THE CONTRARY.

WE DRAW "INSPIRATION" FROM THE QUARK SECTOR. THERE, THE PECULIAR VALUES OF THE MASSES + MIXING ANGLES HAVE LED PEOPLE TO BELIEVE THAT NATURE IS TRYING TO TELL US SOMETHING...

WHAT WE AIM AT IS THE PRESENCE OF SOME NEW FUNDAMENTAL PRINCIPLE (SYMMETRY) THAT DINAMICALLY EXPLAINS WHY MASSES + MIXING ANGLES COME OUT AS THEY DO...

$\boxed{\text{FLAVOR SYMMETRIES}}$

STARTING POINT: WHAT DO THE MASS MATRICES "ROUGHLY" LOOK LIKE?

(EXPLAINING ALL DATA WITH "SMALLEST" AMOUNT OF INPUT)

Table 1
Leading order low energy neutrino Majorana mass matrices m_{LL} consistent with large atmospheric and solar mixing angles, classified according to the rate of neutrinoless double beta decay and the pattern of neutrino masses.

	Type I Small $\beta\beta_{0\nu}$	Type II Large $\beta\beta_{0\nu}$
A Normal hierarchy $m_1^2, m_2^2 \ll m_3^2$	$\beta\beta_{0\nu} \lesssim 0.0082$ eV $\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} \frac{m}{2}$	–
B Inverted hierarchy $m_1^2 \approx m_2^2 \gg m_3^2$	$\beta\beta_{0\nu} \lesssim 0.0082$ eV $\begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \frac{m}{\sqrt{2}}$	$\beta\beta_{0\nu} \gtrsim 0.0085$ eV $\begin{pmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{1}{2} & \frac{1}{2} \end{pmatrix} m$
C Approximate degeneracy $m_1^2 \approx m_2^2 \approx m_3^2$	$\begin{pmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} m$	$\beta\beta_{0\nu} \gtrsim 0.035$ eV diag(1,1,1)m $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} m$

Table 2
Some candidate GUT and Family symmetry groups.

G_{GUT}	G_{Family}
E_6	$SU(3)$
$SO(10)$	$SU(2)$
$SU(5)$	$U(1)$
$SU(5) \times U(1)$	Z_N
$SU(3)^3$	$O(3) \times O(3)$
$SU(4) \times SU(2) \times SU(2)$	$SO(3)$
$SU(3) \times SU(2) \times SU(2) \times U(1)$	$S(3) \times S(3)$
$SU(3) \times SU(2) \times U(1) \times U(1)$	$S(3)$
$SU(3) \times SU(2) \times U(1)$	Nothing

"GOOD" FLAVOR MODELS SOLVE MANY PROBLEMS AT ONCE + LEAD TO NEW EXPERIMENTAL CONSEQUENCES!

Table 2: Order-of-magnitude estimates for θ_{13}.

Texture	θ_{12}	θ_{13}	Perturbations
$m_\nu^{\mathrm{D1}} = m \begin{pmatrix} \delta & -\frac{1}{\sqrt{2}} & \frac{(1-\epsilon)}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{(1+\eta)}{2} & \frac{(1+\eta-\epsilon)}{2} \\ \frac{(1-\epsilon)}{\sqrt{2}} & \frac{(1+\eta-\epsilon)}{2} & \frac{(1+\eta-2\epsilon)}{2} \end{pmatrix}$	$\approx \pi/4$	$\approx \left(\frac{\Delta m^2_{sun}}{\Delta m^2_{atm}}\right)^{1/2}$ ≈ 0	$\epsilon \gg \delta$ $\epsilon \ll \delta$
$m_\nu^{\mathrm{D2}} = m \left[\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + r \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \right] + \delta m_\nu$	$\approx \pi/4$	$\approx \left(\frac{m_e}{m_\mu}\right)^{1/2}$	
$m_\nu^{\mathrm{I}} = m \begin{pmatrix} \delta & -1 & 1 \\ -1 & \eta & \eta \\ 1 & \eta & \eta \end{pmatrix}$	$\approx \pi/4$	$\approx \frac{\Delta m^2_{sun}}{\Delta m^2_{atm}}$ $\ll \frac{\Delta m^2_{sun}}{\Delta m^2_{atm}}$	$\eta \gg \delta$ $\eta \ll \delta$
$m_\nu^{\mathrm{N}} = m \begin{pmatrix} \delta & \epsilon & \epsilon \\ \epsilon & 1+\eta & 1+\eta \\ \epsilon & 1+\eta & 1+\eta \end{pmatrix}$	$O(1)$ $\approx \pi/4$	$\approx \left(\frac{\Delta m^2_{sun}}{\Delta m^2_{atm}}\right)^{1/2}$ $\approx \left(\frac{\Delta m^2_{sun}}{\Delta m^2_{atm}}\right)^{1/3}$	$\eta < \delta \approx \epsilon$ $\delta \approx \epsilon^2 \approx \eta^2$ $\delta \approx \epsilon^2 \quad \eta = 0$

~~a) Degenerate case. If $|m|$ is the common mass, apart from a phase, and taking $s_{13} = 0$, which, as already observed, is a safe approximation in this case, we have $m_{ee} = |m|(c_{12}^2 \pm s_{12}^2)$. Here the phase ambiguity has been reduced to a sign ambiguity~~

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Plato's Fire and the Neutrino Mass Matrix

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Abstract

With the accumulation of many years of solar and atmospheric neutrino oscillation data, the approximate form of the 3×3 neutrino mixing matrix is now known. The theoretical challenge is to understand where this mixing matrix comes from. Recently, a remarkable fact was discovered that for a specific pattern of the neutrino mass matrix at a high scale, any flavor-changing radiative correction will automatically lead to the desired mixing matrix. It was also discovered that the required specific pattern at the high scale can be maintained by the non-Abelian discrete symmetry A_4 which is also the symmetry group of the regular tetrahedron, one of five perfect geometric solids known to Plato who associated it with the element "fire". I discuss this recent development and add to it a new and very simple mechanism for the implementation of the flavor-changing radiative correction.

To appear as a Brief Review in Modern Physics Letters A

CP-VIOLATION IN ν-OSCILLATIONS AND THE BARYON ASYMMETRY OF THE UNIVERSE: ARE THEY RELATED?

ANSWER: WE <u>REALLY</u> DON'T KNOW...

THE CHALLENGE IS TO COMPUTE "LEPTOGENESIS PARAMETERS" FROM LOW-ENERGY OBSERVABLES.

[LEPTOGENESIS: ASSUME HEAVY FERMION (MAJORANA) THAT COUPLES TO ℓ AN ϕ (HIGGS)

RATE ($N \to \ell\phi$) CAN DIFFER FROM RATE ($N \to \bar{\ell}\bar{\phi}$) IF CP IS VIOLATED + "COSMOLOGY" REQUIREMENTS]

$\mathcal{L}_{\text{LEPTOGENESIS}} \supset y_{i\alpha} N^i \ell^\alpha \phi - \frac{M^{ij}}{2} N^i N^j \leftarrow$ HIGH ENERGY $\mathcal{L}$

$\mathcal{L}_{\nu\text{-MASS}} \supset \lambda^{\alpha\beta} (\ell^\alpha \phi)(\ell^\beta \phi) \leftarrow$ LOW ENERGY EFFECTIVE LAGRANGIAN.

THE NUMBER OF "OBSERVABLE" PARAMETERS IS LARGER IN THE ENERGY LAGRANGIAN THAN IN THE LOW-ENERGY EFFECTIVE LAGRANGIAN.

IN ORDER FOR THERE TO BE A RELATIONSHIP, CONSTRAINTS ON $\mathcal{L}_{\text{LEPTOGENESIS}}$ (VIA, SAY, A FLAVOR STRUCTURE) ARE <u>REQUIRED</u>. WILL WE EVER BE ABLE TO VERIFY WHETHER THESE CONDITIONS ARE INDEED MET? $\Rightarrow$ CURRENT SUBJECT OF (INTENSE) THEORETICAL RESEARCH!

SUMMARY

- WE HAVE LEARNED A LOT ABOUT NEUTRINOS IN THE PAST 5 YEARS ⇒ NEUTRINOS HAVE MASS AND MIX!

- NATURE HAS BEEN <u>VERY KIND</u> THIS FAR - WE HAVE OBSERVED BOTH "ATMOSPHERIC" AND "SOLAR" OSCILLATIONS IN MORE LABORATORY-LIKE CONDITIONS AND WE HAVE THE OPPORTUNITY OF FURTHER PROBING THE NEUTRINO SECTOR WITH REALISTIC NEXT-GENERATION EXPERIMENTS → THIS WHY WE ARE HERE!

- IN ORDER TO LEARN MORE, NEW EXPERIMENTS ARE REQUIRED! WE CANNOT GET U_{e3}, δ, ETC BY "CURRENT" EFFORTS + WITS ALONE.

- THEORETICALLY, WE KNOW VERY LITTLE: THIS IS A <u>DATA</u> <u>DRIVEN</u> FIELD. THIS MEANS THAT ANY EXP'TAL RESULT IS BOUND TO FUNDAMENTALLY SHAPE OUR THINKING

- FINALLY, KEEP IN MIND THAT THERE IS PLENTY OF ROOM FOR SURPRISES:

  - REMEMBER LSND
  - ν SECTOR LEAST EXPLORED IN SM.

    (E.G. ν INTERACTIONS MIGHT BE "DIFFERENT"

- ANY OF THESE "SURPRISES" WOULD ONLY ADD TO OUR THEORETICAL TO-DO LIST + RENDER NEXT-GENERATION LONG-BASELINE ν-OSCILLATION EXPERIMENTS <u>MORE IMPORTANT</u>!