

ASPEN MEETING

FEB 3, 2004

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WHAT HAVE WE LEARNED (FROM OSCILLATION EXPERIMENTS) AND WHAT ARE (SOME) OPEN THEORETICAL QUESTIONS?

OUTLINE

- THE MINIMAL NEW STANDARD MODEL
  - THREE NEUTRINO MIXING FORMALISM
  - WHAT HAS BEEN MEASURED
  - WHAT DON'T WE KNOW (AND HOPE TO MEASURE VIA OSC.)
- THE NON-MINIMAL NEW STANDARD MODEL
  - INCLUDING LSND
- WHAT HAVE THEORISTS REALLY LEARNED?
  - WHAT ARE THE QUESTIONS THAT DRIVE "THEORETICAL" RESEARCH?
- WHAT CAN WE LEARN FROM MIXING MATRIX ELEMENTS?
  - $|U_{e3}|$
  - $|U_{\mu 3}|$  A.K.A THE ATMOSPHERIC MIXING ANGLE

# THE MINIMAL NEW STANDARD MODEL

## NEUTRINOS CHANGE FLAVOR!

THE SM. OF ELECTROWEAK INTERACTIONS CANNOT ACCOMMODATE THIS FACT  $\Rightarrow$  NEW PHYSICS!

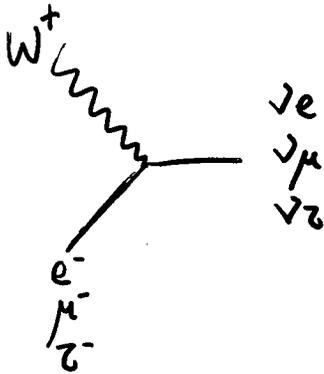
THE SIMPLEST AND ONLY IDEA STILL STANDING THAT CAN SIMULTANEOUSLY ADDRESS ALL OF THE OBSERVED "OSCILLATION PHENOMENA" IS TO POSTULATE THAT:

- NEUTRINOS HAVE MASS
- MASS EIGENSTATES  $\neq$  WEAK (FLAVOR) EIGENSTATES.

WE HAVE ALREADY HEARD IN THE PREVIOUS 3 TALKS WHAT THE EXPERIMENTAL EVIDENCE IS. I'LL BRIEFLY SUMMARIZE THE "COMBINED" SITUATION.

ISI: WHAT HAPPENS IF  $\Delta S_{ND}$  IS NOT RELATED TO NEUTRINO OSCILLATIONS:

# 3 FLAVOR MIXING



VS.

- $\nu_1$  w/ MASS  $m_1$
- $\nu_2$  w/ MASS  $m_2$
- $\nu_3$  w/ MASS  $m_3$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

(+)

$$m_1^2 < m_2^2$$

$$\Delta m_{12}^2 < |\Delta m_{13}^2|$$

↑  
LEPTONIC MIXING MATRIX

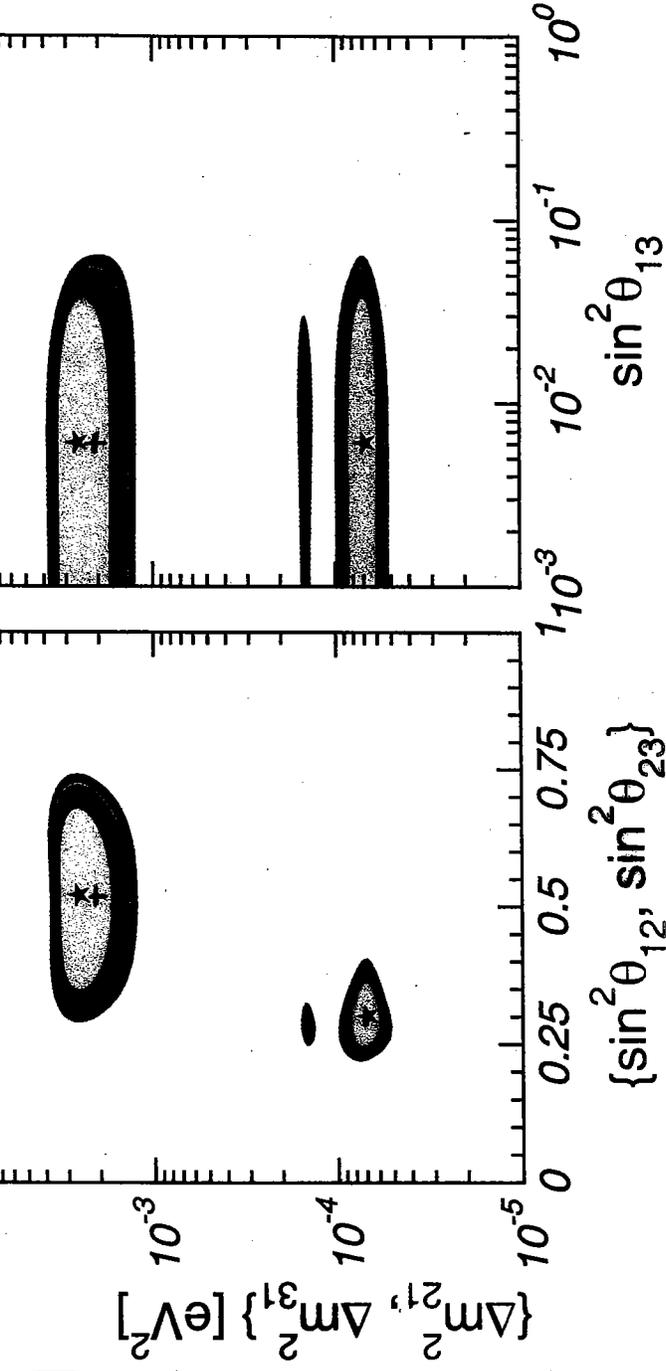
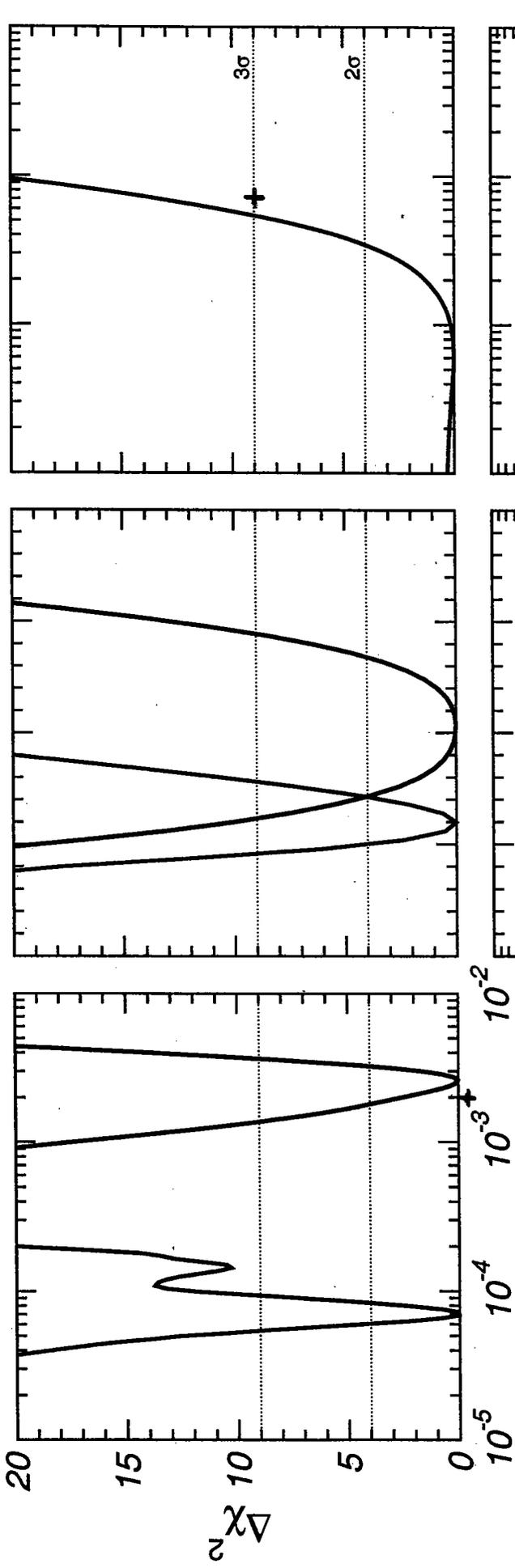
U PARAMETERIZED BY

- $\theta_{12}, \theta_{13}, \theta_{23}$  → MIXING ANGLES
- $\delta$  → DIRAC PHASE
- $\phi_1, \phi_2$  → MAJORANA PHASES (IRRELEVANT FOR OSC.)

$$U_{[MNS]} = \begin{pmatrix} \cos\theta_{12} \cos\theta_{13} & \sin\theta_{12} \cos\theta_{13} & \sin\theta_{13} e^{-i\delta} \\ * & * & \sin\theta_{23} \cos\theta_{13} \\ * & * & \cos\theta_{23} \cos\theta_{13} \end{pmatrix}$$

OSCILLATIONS ALSO SENSITIVE TO  $\Delta m_{12}^2, \Delta m_{13}^2$

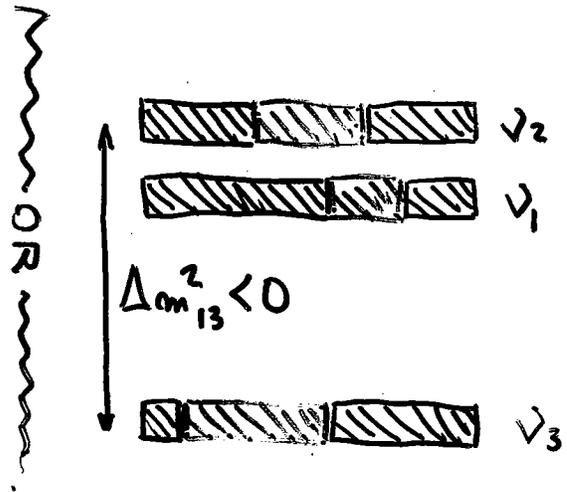
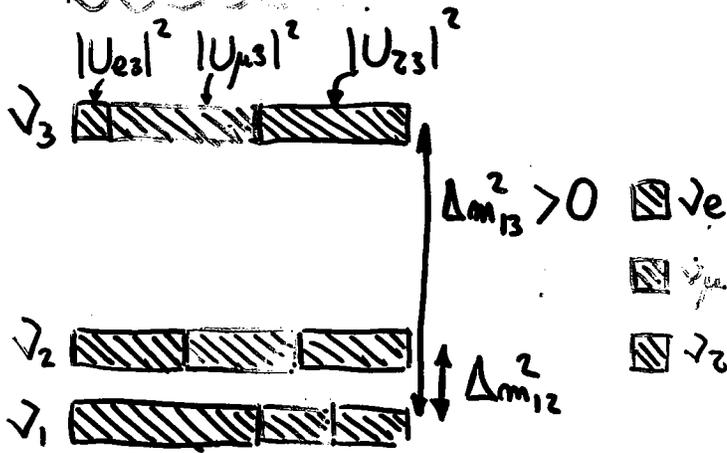
6 MEASURABLE QUANTITIES IN OSC. EXPERIMENTS



99, 95, 99, 3σ C.L.

MALTONI ET AL  
HEP-PH/0309130

IN SUMMARY



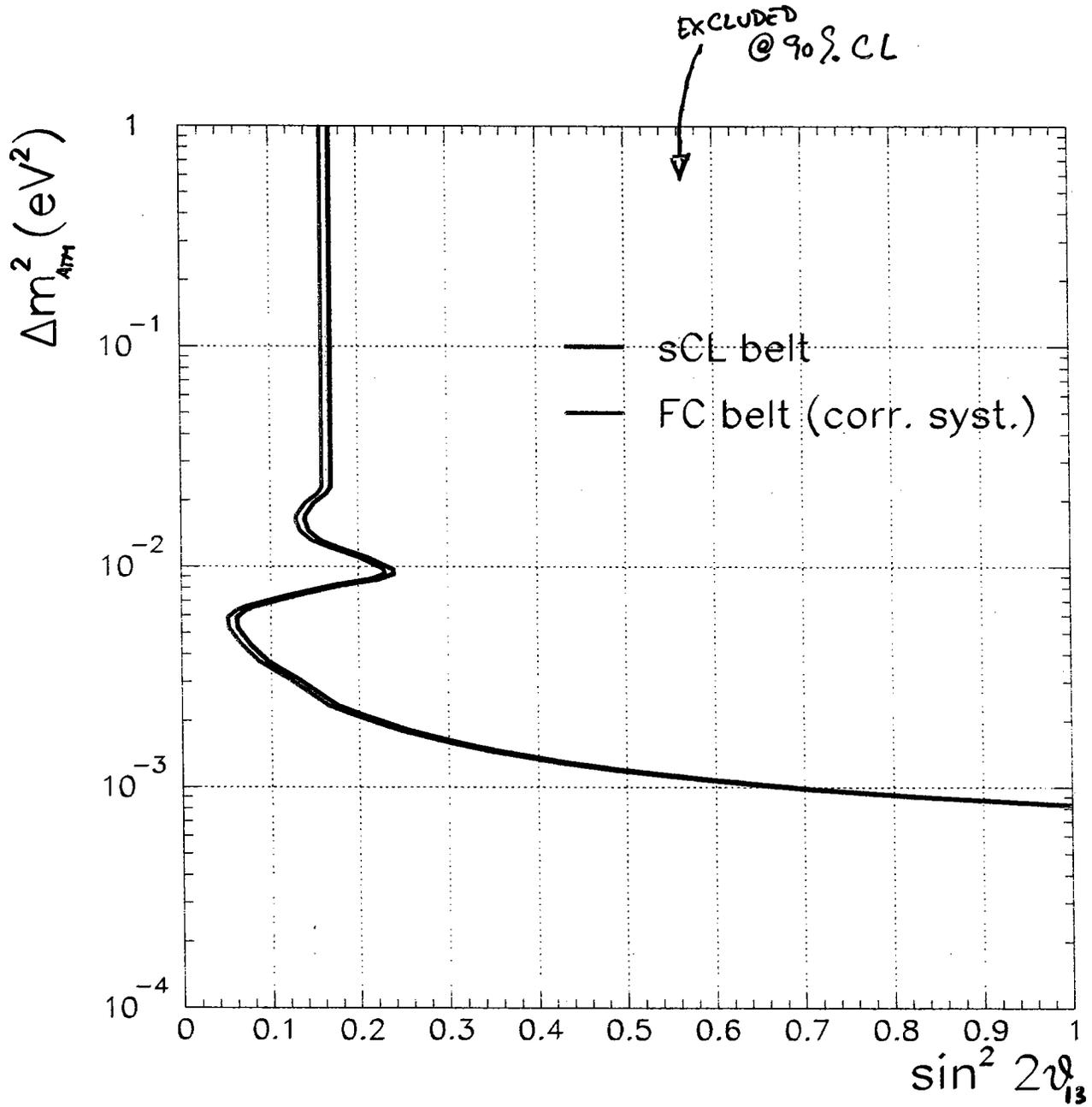
WE KNOW (3σ)

- $\Delta m_{12}^2, |\Delta m_{13}^2| \rightarrow 0.023 < \frac{\Delta m_{12}^2}{|\Delta m_{13}^2|} < 0.070$
- $\theta_{12}, \theta_{23} \rightarrow \begin{cases} 0.22 < \cos 2\theta_{12} < 0.56 \\ -0.44 < \cos 2\theta_{23} < 0.44 \end{cases}$ 

$\nu_1$  "MOSTLY"  $\nu_e$   
 $\cos 2\theta = 0 \Rightarrow$  "MAXIMAL MIXING"
- $\theta_{13}$  "SMALL"  $\rightarrow \sin^2 \theta_{13} < 0.07$

WE WANT TO FIND OUT

- $\text{SIGN}[\Delta m_{13}^2] \rightarrow$  INVERTED OR NORMAL HIERARCHY?
- is  $|U_{e3}| \neq 0 \rightarrow$  HOW LARGE IS IT?
- $\delta = ? \rightarrow$  IS CP VIOLATED IN LEPTONIC SECTOR?
- $\text{is } \cos 2\theta_{23} = 0$   $[|U_{\mu 3}|^2 = 1/2]$   $\rightarrow$ 
  - is  $\nu_3$  "MOSTLY"  $\nu_\mu$ ?
  - is  $\nu_3$  "MOSTLY"  $\nu_\tau$ ?
- $\text{is } \cos 2\theta_{23} > 0$
- $\text{is } \cos 2\theta_{23} < 0$



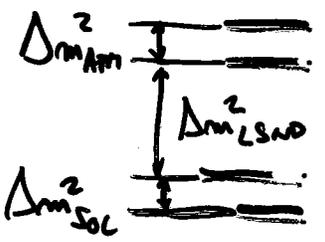
ATM + SOLAR DATA TELL YOU

THAT  $|U_{e3}|$  IS SMALL (NOT CLOSE TO 1)

# THE NON-MINIMAL NEW S.M. - WHAT SHOULD WE DO REGARDING LSND ?

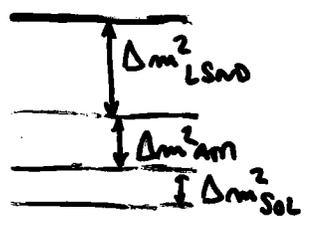
- WAIT FOR MINIBOONE. → (PLUS PREVIOUS PAPER)
- ADD STERILE NEUTRINO(S).

2+2



"RULED OUT"  
BY SOLAR +  
ATM DATA

3+1



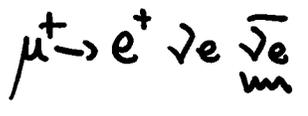
DISFAVORED  
BY LOW ENERGY  
 $\nu_{\mu} \rightarrow \nu_{\mu}$  DATA  
 $\nu_e \rightarrow \nu_e$

3+2 (3+1+1)

BETTER  
FIT, SOMEWHAT  
CONTRIVED...

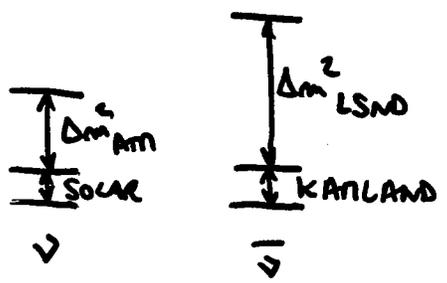
- OTHERS

RARE  $\mu$ -DECAY



"RULED OUT"  
BY KARLEN II  
DATA

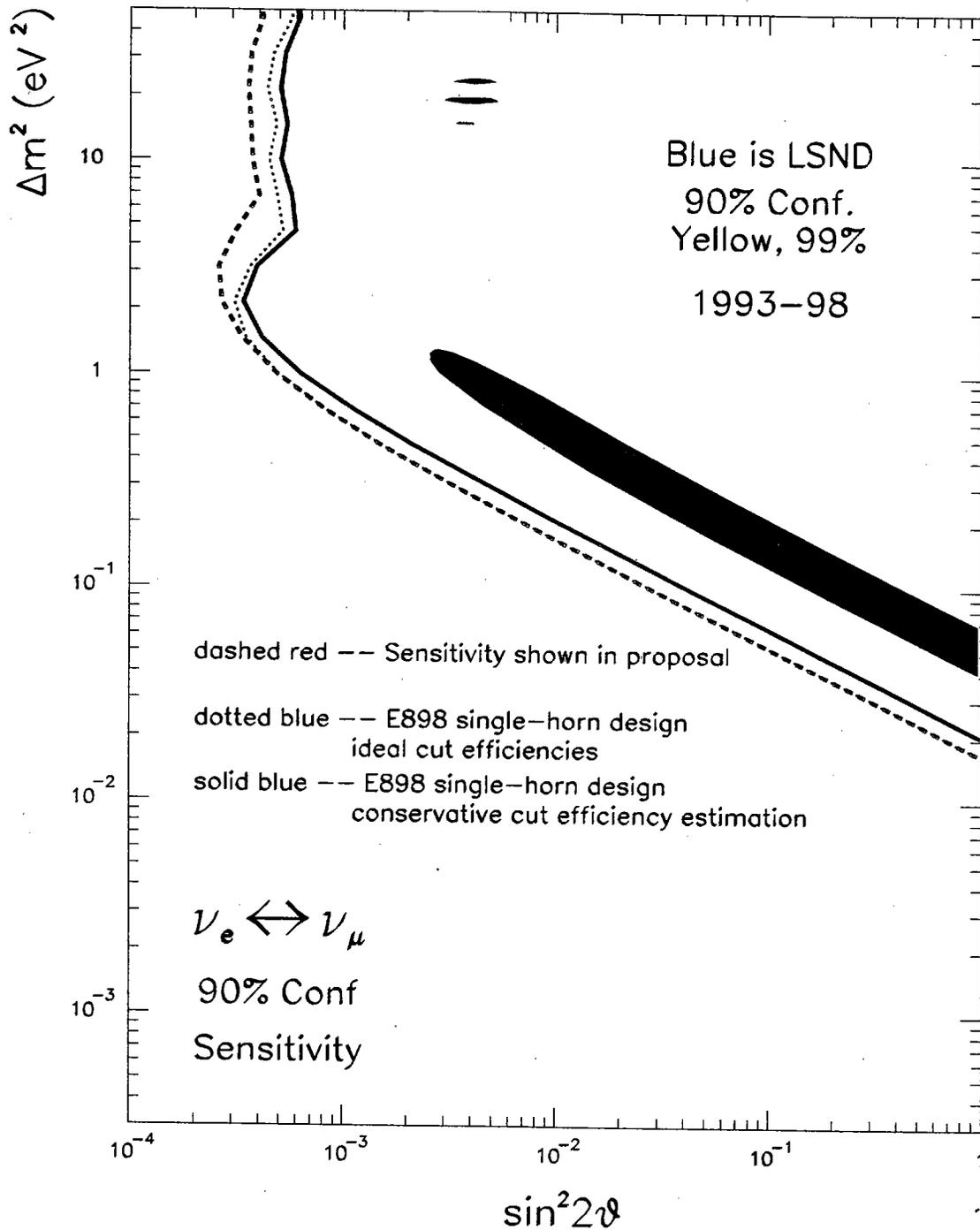
C.P.T-VIOLATION



"STRONGLY" DISFAVORED  
BY ATMOSPHERIC DATA  
(...)



# SENSITIVITY OF THE MIMI BOONE EXPERIMENT



START OF DATA TAKING → END OF SOME 2000

WHAT HAVE "THEORISTS" LEARNED, I.E. WHAT ARE THEY WORRYING ABOUT?

1- THERE IS "NONTRIVIAL" NEW PHYSICS BEYOND THE S.M. OF ELECTROWEAK INT.\*!

2- NEUTRINO MASSES ARE NON-ZERO. HOWEVER  $\Rightarrow$

3- NEUTRINO MIXING IS QUALITATIVELY DIFFERENT FROM QUARK MIXING

$$U_{CKM} \sim \begin{pmatrix} 1 & \epsilon & \epsilon^3 \\ \epsilon & 1 & \epsilon^2 \\ \epsilon^3 & \epsilon^2 & 1 \end{pmatrix} ; \epsilon \sim \sin \theta_c \sim 0.2$$

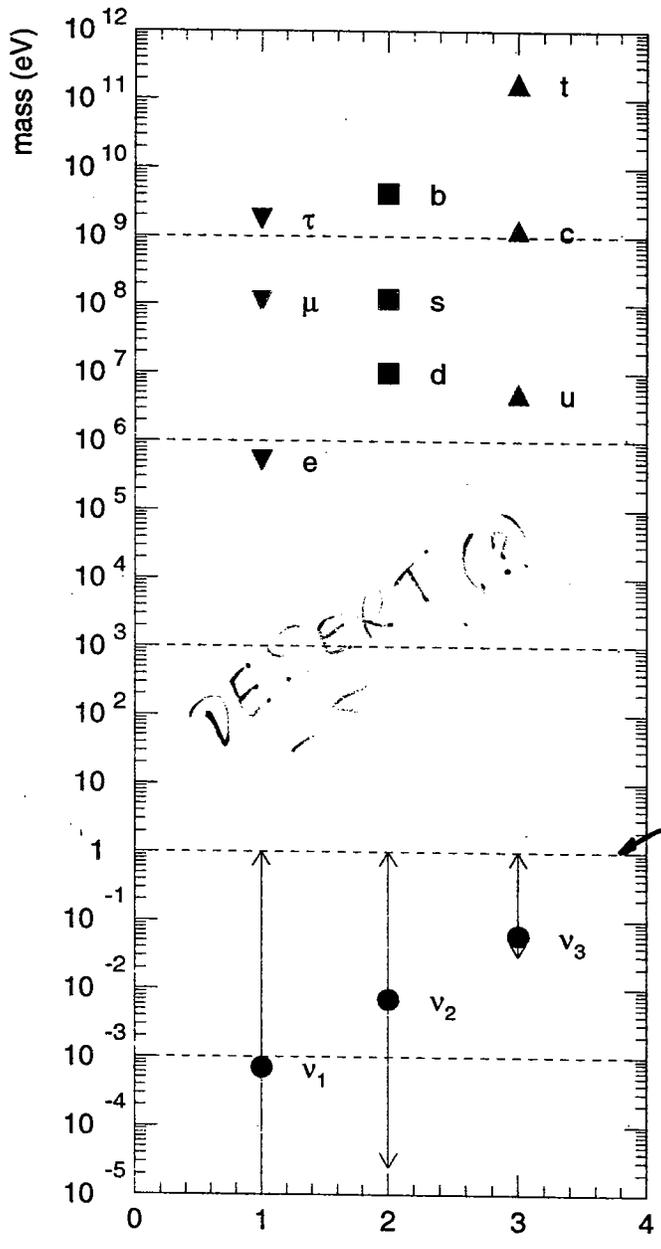
$$U_{MNS} \sim \begin{pmatrix} 1 & 1 & U_{e3} \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} ; U_{e3} \lesssim 0.2$$

\* S.M.  $\Rightarrow$  RULES

- GAUGE SYMMETRY  $SU(3) \times SU(2) \times U(1)$
- PARTICLE CONTENT  $Q, u, d, L, e, \text{HIGGS}$
- MOST GENERAL, RENORMALIZABLE LAGRANGIAN
- NOTHING ELSE

$\Rightarrow$  NEUTRINO MASSES REQUIRE A NON-TRIVIAL MODIFICATION OF THESE RULES.

# NEUTRINO MASSES ARE REALLY TINY!



DESERT (?)

UPPER BOUND FROM OSCILLATIONS + TRITIUM BETA DECAY + COSMOLOGY (CONSERVATIVE)

NEW: WMAP :  $\sum m_\nu < 0.7 \text{ eV}$

ARE THEY QUALITATIVELY DIFFERENT?

- ARE  $\nu$  MAJORANA FERMIONS?
- IS THE ORIGIN OF THEIR MASS DIFFERENT FROM  $e, m, \mu, \tau$ ?

# HOW DO WE MODIFY THE S.M. ?

- WE DON'T KNOW! (THERE IS VERY LITTLE INFO!)



- THERE SEVERAL, COMPLETELY DIFFERENT, WAYS OF ADDRESSING NEUTRINO MASSES. THEY ARE ALL INTERESTING IN THEIR OWN WAY...



- LEAD TO OTHER OBSERVABLE CONSEQUENCES
- ARE "SIMPLE"
- ADDRESS OTHER OUTSTANDING PROBLEMS
- ARISE AS CONSEQUENCES OF OTHER NEW PHYSICS SCENARIOS (SUSY, GUT'S, EXTRA-DIM'S, ETC)..
- ...

- WE CLEARLY NEED MORE EXPERIMENTAL INPUT!  
(AND IT IS COMING IN THE NEAR/INTERMEDIATE FUTURE)

- ONE OFTEN HEARS THE STATEMENT THAT LEPTONIC MIXING IS "STRANGE", OR THAT IT REQUIRES AN EXPLANATION

- THE ZERO<sup>TH</sup> ORDER REASON FOR THIS IS THAT WE HAVE "GROWN ACCUSTOMED" TO THE SMALL QUARK MIXING ANGLES...

WHY CARE ABOUT THE MIXING ANGLES?

- IN THE QUARK SECTOR, THE SMALL MIXING ANGLES ARE INTERPRETED, TOGETHER WITH THE HIERARCHICAL QUARK MASSES AS EVIDENCE FOR EXTRA STRUCTURE IN THE S.M., I.E., SOME UNDERLYING DYNAMICAL PRINCIPLE (SYMMETRY) CAPABLE OF TELLING ONE QUARK FLAVOR FROM ANOTHER

- THE SAME "MUST BE TRUE" OF THE LEPTONS, AS IN MANY SCENARIOS QUARKS AND LEPTONS UNIFY AT SOME HIGH ENERGY SCALE...

HENCE THERE SHOULD BE EXTRA STRUCTURE ADDED TO THE S.M. THAT WILL NATURALLY EXPLAIN THE LARGE LEPTONIC MIXING...

... OR IS THERE?

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

10

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 $m_1^2, m_2^2 \ll m_3^2$	$\beta\beta_{0\nu} \lesssim 0.0082 \text{ eV}$ $\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} \frac{m}{2}$	-
B Inverted hierarchy $m_1^2 \approx m_2^2 \gg m_3^2$	$\beta\beta_{0\nu} \lesssim 0.0082 \text{ eV}$ $\begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \frac{m}{\sqrt{2}}$	$\beta\beta_{0\nu} \gtrsim 0.0085 \text{ eV}$ $\begin{pmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{1}{2} & \frac{1}{2} \end{pmatrix} m$
C Approximate degeneracy $m_1^2 \approx m_2^2 \approx m_3^2$	$\begin{pmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} m$	$\beta\beta_{0\nu} \gtrsim 0.035 \text{ eV}$ 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!

## WE SHOULD BACK-UP AND RE-EXAMINE THIS:

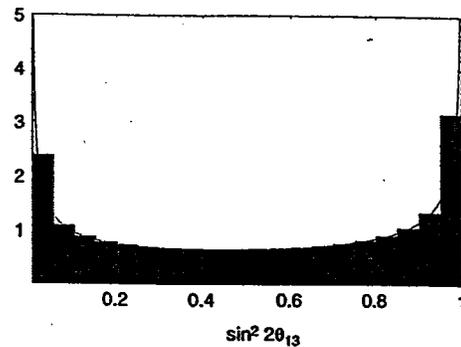
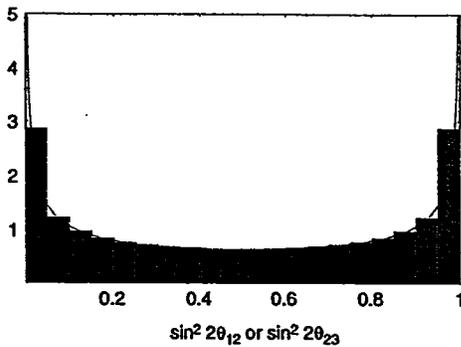
- QUARK MIXING IS VERY STRANGE! THIS IS WHY WE ARE CONVINCED THAT THERE IS SOME "HINT" CONTAINED IN THE CKM MATRIX.
- NEUTRINO (LEPTON) MIXING, ON THE OTHER HAND, SEEMS QUITE "ORDINARY." MAYBE IT IS WHAT WE SHOULD EXPECT IF THERE IS NO FUNDAMENTAL PRINCIPLE BEHIND IT...

## IMMEDIATE COMPLAINTS:

- WHAT ABOUT THE HIERARCHICAL CHARGED LEPTON MASSES?
- WE DON'T KNOW HOW HIERARCHICAL THE NEUTRINO MASSES ARE...
- WHAT ABOUT GUTS?

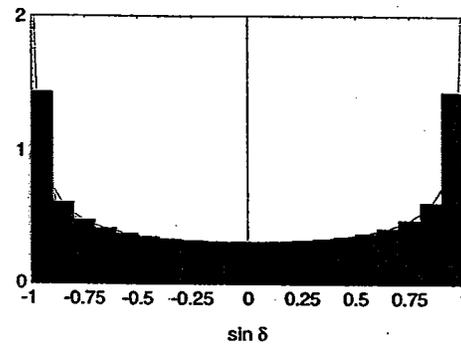
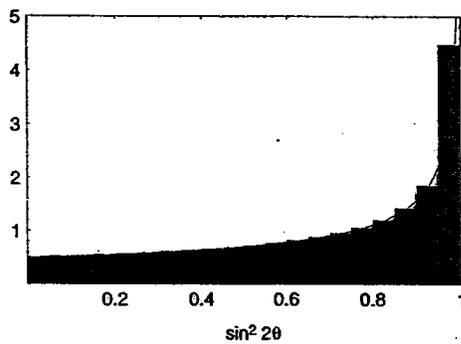
ALL OF THESE ISSUES CAN BE EASILY TAKEN CARE OF, AND THE LEPTONIC MIXING MATRIX MAY STILL TURN OUT TO BE STRUCTURELESS.

CAN ONE QUANTIFY THIS?



O(3)

Figure 1: Distributions in (a)  $\sin^2 2\theta_{12}$  or  $\sin^2 2\theta_{23}$  and (b)  $\sin^2 2\theta_{13}$  for the case of real mass matrices.



U(3)

Figure 2: Distributions in (a)  $\sin^2 2\theta_{12}$  or  $\sin^2 2\theta_{13}$  or  $\sin^2 2\theta_{23}$  and (b)  $\sin \delta$  for the case of complex mass matrices.

NEUTRINO FLAVOR WITHOUT FLAVOR?

⇒ SIMPLEST BOTTOM-UP APPROACH! ~~↔~~

IS THE MNS MATRIX "TYPICAL" OF WHAT

YOU WOULD EXPECT IF THERE WAS NO

FUNDAMENTAL DISTINCTION AMONG THE 3

NEUTRINOS. I.E. IS THE MNS MATRIX

"ANY OLD" 3x3 UNITARY MATRIX?

TABLE I:  $\sin^2 \theta_{ij}$  in the MNS and CKM mixing matrices, according to the PDG parametrization [1]. In square brackets we quote the currently allowed experimental values for the CKM (MNS) entries at the 90% (three sigma) confidence level.

"angle"	CKM [90% expt.]	MNS [ $3\sigma$ expt.]
$\sin^2 \theta_{13}$	$ V_{ub} ^2 [(6.2 - 23) \times 10^{-6}]$	$ U_{e3} ^2 [0 - 0.05]$
$\sin^2 \theta_{12}$	$\sin^2 \theta_C [0.048 - 0.051]$	$\sin^2 \theta_{\text{sol}} [0.2 - 0.5]$
$\sin^2 \theta_{23}$	$ V_{cb} ^2 [(1.4 - 1.9) \times 10^{-3}]$	$\sin^2 \theta_{\text{atm}} [0.35 - 0.65]$

"ANARCHY"\* IN THE MIXING MATRIX MIGHT BE EXPRESSED AS THE FOLLOWING "MODEL":

WE PREDICT THAT THE MIXING MATRIX IS A "RANDOM VARIABLE" DRAWN FROM A FLAT DISTRIBUTION OF UNITARY  $3 \times 3$  MATRIX.

GIVEN NATURE'S "DRAW", HOW LIKELY IS IT THAT THIS HYPOTHESIS IS CORRECT?

SEE ADG, NURAYANA

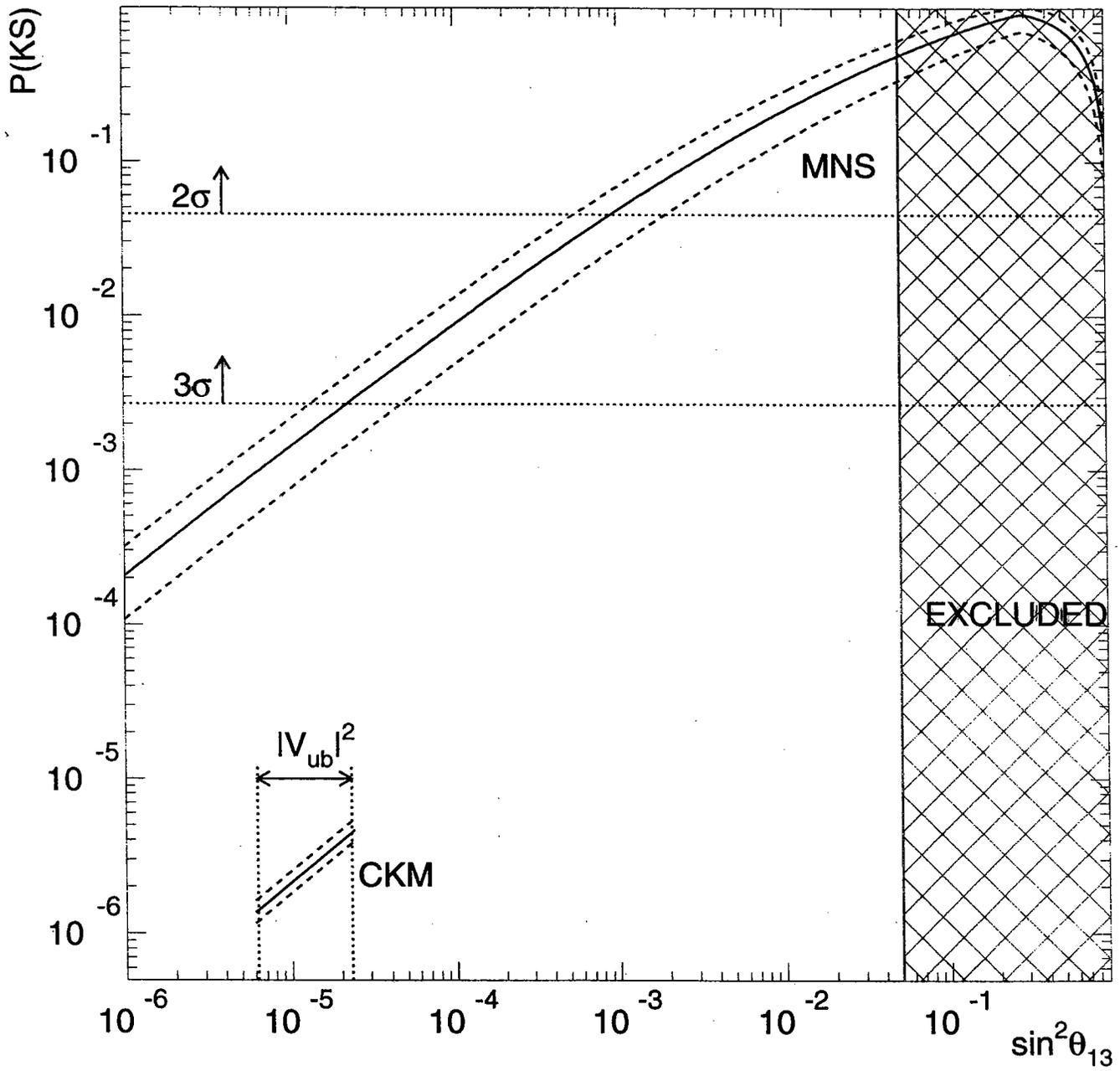
HEP-TH/0301050

PLB573, 94(2003)

\* HALL, NURAYANA, WEINER

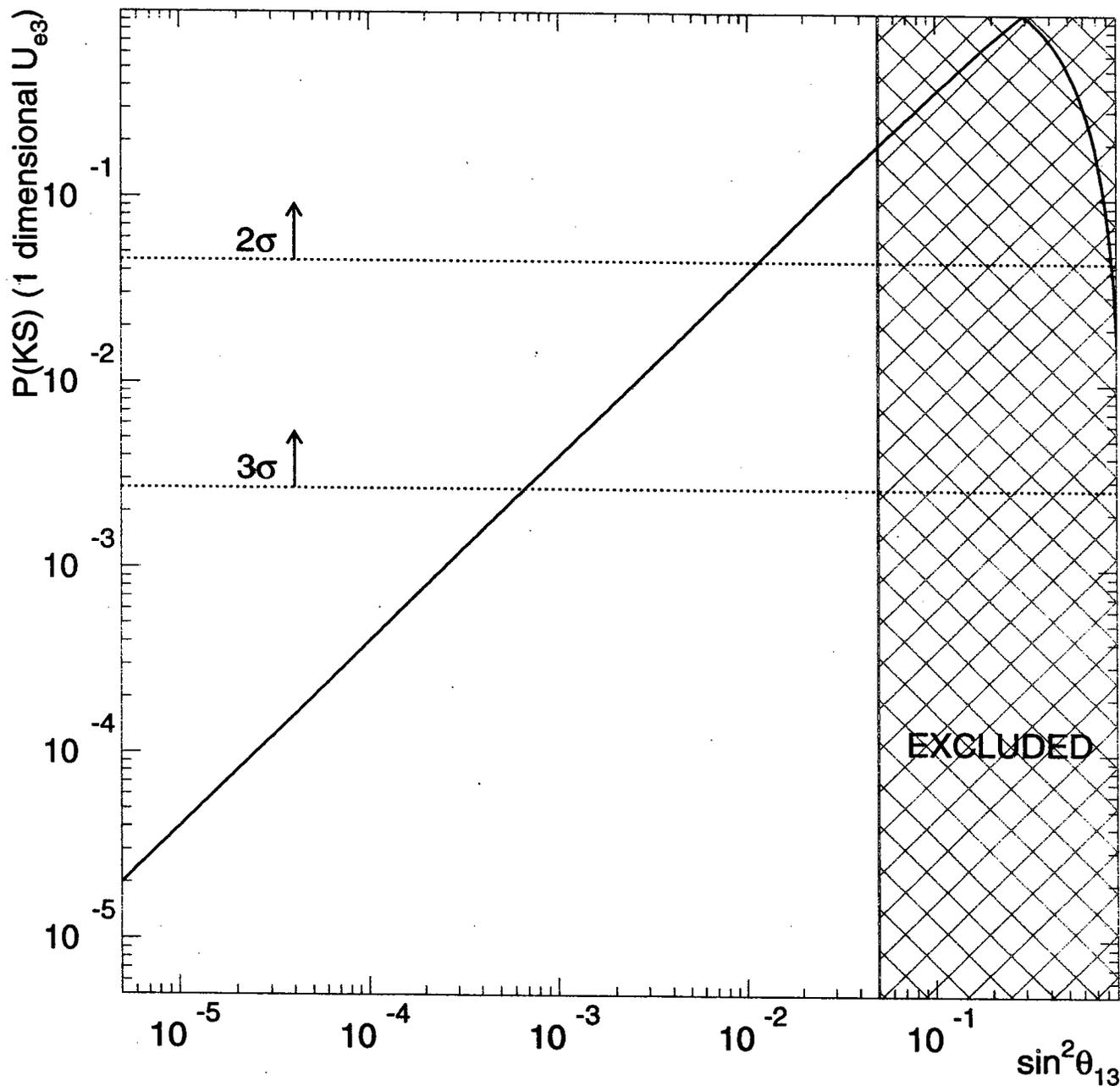
# "C.L." OF ANARCHICAL HYPOTHESIS

PLB 573, 94(2003)



# ANARCHICAL PREDICTION FOR $\tan^2 \theta_{13}$

PLB 573 94 (2003)



$$|U_{e3}|^2 > 0.011 \text{ @ } 2\sigma \text{ LEVEL}$$

# COMMENTS ON ANARCHY

- THE FACT THAT THIS MODEL WORKS DOES NOT MEAN THAT FLAVOR SYMMETRIES ARE DISFAVORED. THEY DO, HOWEVER, HAVE THE "BURDEN OF PROOF"
- IT SAYS NOTHING ABOUT THE MASSES, MASS-HIERARCHIES, ETC.
- DOES IT MEAN ANYTHING "DEEP" ?

## LESS IMMEDIATE COMPLAINT:

⇒ WHAT ABOUT THE "MAXIMAL MIXING" IN THE ATM SECTOR? DOESN'T THAT SEEM TO INDICATE THAT NATURE IS TRYING TO TELL US SOMETHING?

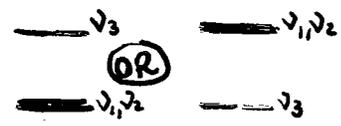
MORE USEFUL: IF MAXIMAL MIXING IS SOMEHOW "IMPRINTED" IN THE MASS MATRIX, CAN WE TELL EXPERIMENTALLY?

HOW WELL WOULD WE NEED TO MEASURE

$\theta_{13}$  ?

$\theta_{23}$  AN STRUCTURE: HOW FAR IS  $\theta_{23}$   
 ALLOWED TO DEVIATE FROM  $\pi/4$  IF MAXIMAL  
 MIXING IS FUNDAMENTAL? [hep-ph/0401220]

**APPROACH**: CHOOSE ZEROth ORDER MASS MATRIX  
 (MAJORANA MASS MATRIX IN THE WEAK BASIS WHERE  
 THE CHARGED LEPTONS + CHARGED CURRENT ARE  
 DIAGONAL) THAT LEADS TO

-  $m_1^2 = m_2^2$   
 -  $\nu_3 = 50\% \nu_\mu, 50\% \nu_\tau, 0\% \nu_e$   $\Rightarrow$  

THEN ADD PERTURBATION MASS MATRIX  
 (ORIGIN IRRELEVANT) WHICH IS "RANDOM".  
 DETERMINE THE SIZE OF THE PERTURBATION  
 ASSUMING THAT IT IS RESPONSIBLE FOR  
 SPLITTING THE  $m_1^2 = m_2^2$  EQUALITY.

EXTRACT VALUES FOR  $\theta_{12}, \theta_{13}, \theta_{23}$  GIVEN  
 THE RANDOM PERTURBATION.

RESULTS  $\rightsquigarrow$

EXAMPLES  $\rightsquigarrow$

## EXAMPLES

$$\frac{m_0}{2} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & -1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} m_0$$

$\nearrow U_{e3}$   
 $\searrow U_{\mu 3}$

$$m_0 \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/2 & -1/2 \\ 0 & -1/2 & 1/2 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & -1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} m_0$$

$$\frac{m_0}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 1/2 & -1/2 & -1/\sqrt{2} \\ 1/2 & -1/2 & -1/\sqrt{2} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix} U^T$$

## "PERTURBATION"

$$m_1 \begin{pmatrix} a & d & e \\ d & b & f \\ e & f & c \end{pmatrix}$$

$m_1 \ll m_0$   
 $a, b, c, d, e, f \sim \mathcal{O}(1)$  RANDOM  
NUMBERS

TABLE I: Order of magnitude for the average value of the leptonic mixing parameters for the different neutrino mass-textures. See Sec. III for more detail. Also included are the expectations for an anarchical mixing matrix [5, 10].

Texture (Sec.)	$ U_{e3} $	$ \cos 2\theta_{23} $	Solar Angle
Normal Hierarchy (IIIA)	$\sqrt{\Delta m_{12}^2/\Delta m_{13}^2}$	$\sqrt{\Delta m_{12}^2/\Delta m_{13}^2}$	O(1)
Inverted Hierarchy (IIIB)	$\Delta m_{12}^2/ \Delta m_{13}^2 $	$\Delta m_{12}^2/ \Delta m_{13}^2 $	O(1)
Inverted Hierarchy, Traceless (IIIC)	$\Delta m_{12}^2/ \Delta m_{13}^2 $	$\Delta m_{12}^2/ \Delta m_{13}^2 $	$ \sin \theta_{12}  \sim \Delta m_{12}^2/ \Delta m_{13}^2 $
Inverted Hierarchy, Bi-maximal III(D)	$\Delta m_{12}^2/ \Delta m_{13}^2 $	$\Delta m_{12}^2/ \Delta m_{13}^2 $	$ \cos 2\theta_{12}  \sim \Delta m_{12}^2/ \Delta m_{13}^2 $
Anarchy	> 0.1	O(1)	O(1)

•  $|U_{e3}| \sim \cos 2\theta_{23}$

DEPENDENCY ON MASS-HIERARCHY:

-  $|\cos 2\theta_{23}| \lesssim 0.2$  [NORMAL HIERARCHY]

-  $|\cos 2\theta_{23}| \lesssim 0.04$  [INVERTED HIERARCHY]

AN ORDER 10% MEASUREMENT OF  $\cos 2\theta_{23}$

(1% MEASUREMENT OF  $\sin^2 2\theta_{23}$  IF  $\sin^2 2\theta_{23} = 1$ ) WILL START

TO TELL US WHETHER THERE IS SOMETHING "SPECIAL" ABOUT ATMOSPHERIC MIXING...

# CONCLUSIONS SUMMARY

• NEUTRINO MASSES REPRESENT THE ONLY PALIABLE EVIDENCE THAT THERE IS PHYSICS BEYOND THE STANDARD MODEL.

• THE AMOUNT OF INFORMATION WE HAVE IS VERY LIMITED  $\Rightarrow$  WE NEED MORE EXPERIMENTAL RESULTS [NEUTRINO PHYSICS = DATA DRIVEN FIELD]

• WE WILL LEARN MUCH MORE FROM:

- NEUTRINO OSCILLATIONS ( $\theta_{13}, \delta, \theta_{23}$ , ETC)
- CHARGED LEPTON FLAVOR VIOLATION ( $\mu \rightarrow e \gamma$ , ...)
- **NEUTRINOLESS DOUBLE BETA DECAY**

- ANYBODY ELSE THAT CAN TELL US WHAT THIS NEW PHYSICS IS!

• IN PARTICULAR, NEUTRINO OSCILLATION EXPERIMENTS WILL TELL US WHETHER THERE IS "STRUCTURE" IN THE LEPTONIC MIXING MATRIX

i.e. is 
$$\begin{cases} |U_{e3}|^2 \gtrsim 0.01 \\ |\cos 2\theta_{23}| \gtrsim 0.1 \end{cases} ?$$

ANSWERING THIS WOULD TEACH US SOMETHING NONTRIVIAL ABOUT NATURE.

• OUR MINIMAL UNDERSTANDING CERTAINLY SEEMS TO BE ON THE RIGHT TRACK. HOWEVER IT MIGHT STILL BE GROSSLY INCOMPLETE. THERE IS PLENTY OF ROOM FOR SURPRISES!

REMEMBER LSND (+) THE FACT THAT WE MAY BE PROBING PHYSICAL "ORDERS OF MAGNITUDE" AWAY.

