Christchurch, New-Zealand
May 26, 2008

The speaker does not take any responsibility
for the title of his talk

Still he will do his best to make sense out of it

Where are we?
Where are we going?

A. Yu. Smirnov

International Centre for Theoretical Physics, Trieste, Italy
Institute for Nuclear Research, RAS, Moscow, Russia

Beloved question of ν physicists

which can be explained by elusive character of the subject of research

``Where are we?''

HEP SPIRES: 52 papers found

13 papers on neutrinos

J. N. Bahcall – 6, on solar neutrinos
B. Kayser – 2

Not only neutrino physicists are lost:

Where we are in

particle physics – 2
high energy physics – 2
heavy ion collisions – 2
non-baryonic DM – 2
. . .

Can you guess?

string theory – 1

confidence and determination

The SSC: where are we now?

no comment

in addition

Encoding: S. Weinberg, S. L. Glashow, L. Lederman among those who asked

Variations on the theme:

How it started and Where we are

and where do we stand

and where should we go

and we're headed and why

coming from

Even more profound: What we are?

J. Ellis (with reference to P Gauguin)

Where are we in time

1908 Rutherford: the Nobel prize in chemistry

1868 New Zealand time

1918

1928 The Dirac equation

1938 Majorana

1948 Artificial production of pions (Lattes, Gardner)

1958 Helicity of neutrinos: Goldhaber, Grodzins Sunyar

1968 First Davis result, the birth of the solar neutrino problem

1978 Wolfenstein: neutrino oscillation in matter

1988 The birth of the atmospheric neutrino problem: Kamiokande II

1998 Evidence of oscillations of atmospheric neutrinos

2008 ??? Few month before the start of LHC

... in space

SuperKamiokande
Tokai

INO

CERN
Gran Sasso

Fermilab

in 3D:

IceCube

for orientation..

just in case if one wants to construct underground laboratory or accelerator in Christchurch

... in extra dimensions:

somewhere on the EW brane

... in the field of neutrino physics

- Conquest territory: the standard neutrino scenario
- Where are we in understanding neutrino masses and mixing
- Beyond the standard neutrino scenario
- Future which we know
- Future which we don't know can imagine

Standard neutrino scenario

1. Neutrino interactions are described by the Standard (electroweak) model.

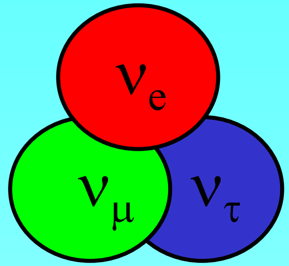
2. There are only 3 types of light neutrinos: three flavors and three mass states.

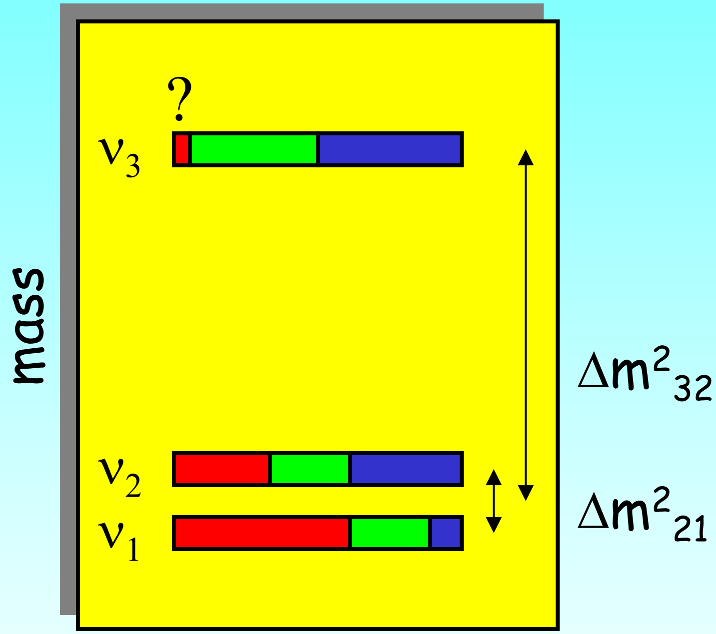
3. Neutrinos are massive. Neutrino masses are in the sub-eV range - much smaller than masses of charge leptons and quarks.

4. Neutrinos mix. There are two large mixings and one small or zero mixing. Pattern of lepton mixing strongly differs from that of quarks.

5. Masses and mixing have pure vacuum origin; they are generated at the EW and probably higher mass scales.

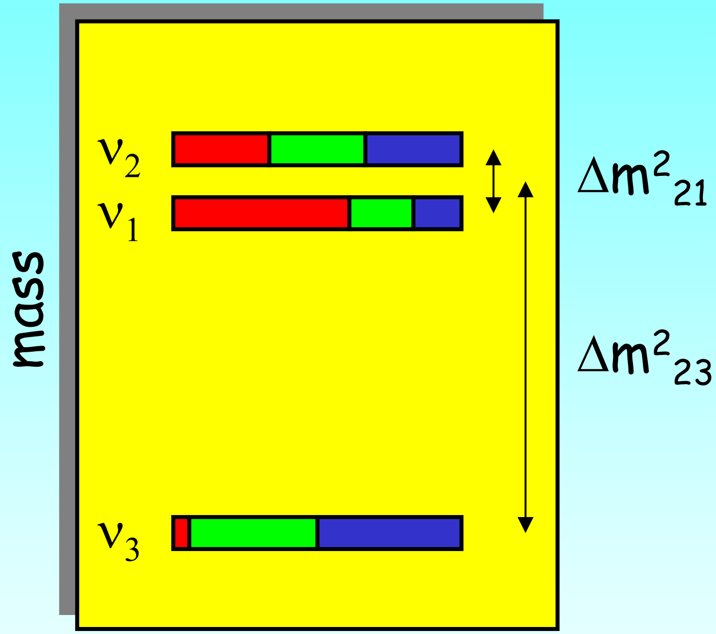
Spectrum





Normal mass hierarchy

?

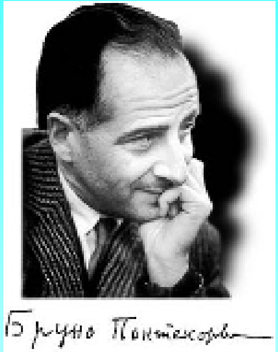


Inverted mass hierarchy

$$\nu_f = U_{PMNS}\, \nu_{mass}$$

$$U_{PMNS} = U_{23}\; I_\delta\, U_{13}\, I_{-\delta}\, U_{12}$$

Standard scenario

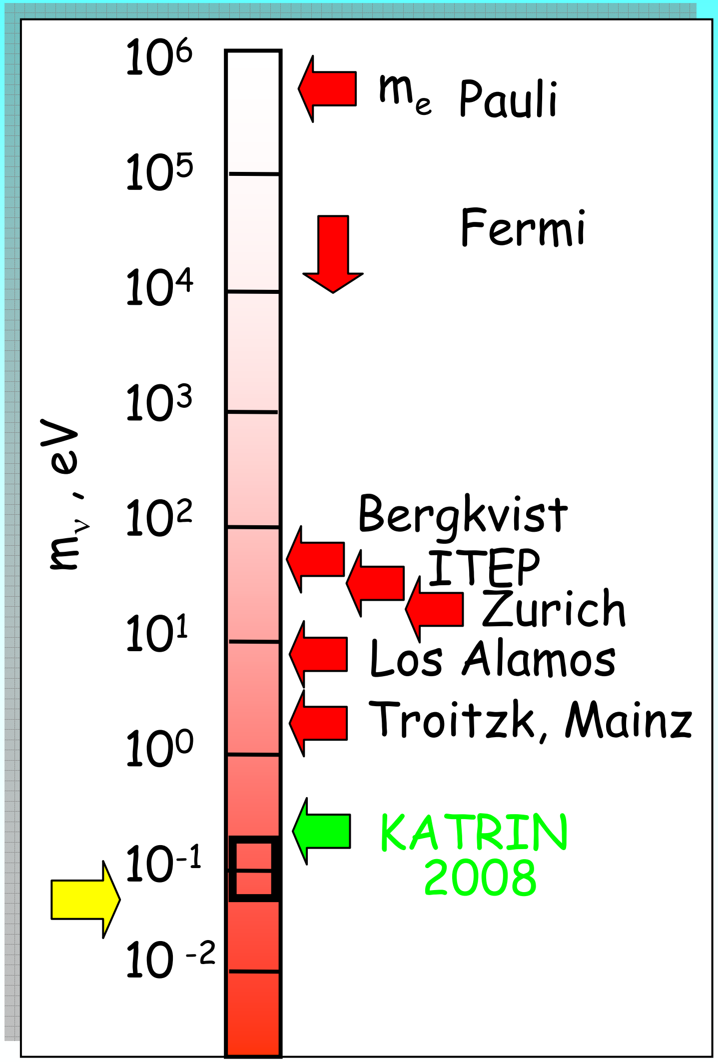
Result of work of several generations of neutrino physicists

collective efforts of experimentalists and theoreticians

Our conquest territory. Basis and Starting point for further advance. Reference scenario

Summary of results of the first phase of studies of neutrino mass and mixing

``neutrino time"



Interactions

Gauge interactions are well known (SM) and well checked

Yukawa couplings with Higgs boson(s) - related to existence of the RH neutrinos are unknown; they are relevant for leptogenesis

Interaction with complex systems:
nucleons and nuclei, νN-, νA: open questions

problem of strong interactions.

Single-pion production, forward production

In some cases - neutrinos are unique:
provide axial vector current → axial vector anomaly →
interactions of Z, γ, ω (for MiniBooNE) *J Harley, C.T. Hill, R. Hill*

Nuclear physics for $\beta\beta$-decay

Rare neutrino processes relevant for astrophysics,
$\nu\bar{\nu}$- pair production, etc.

Propagation

Theory of ν-oscillations in vacuum: still some discussions

``Eternal Questions''

Paradoxes of ν– oscillations

- momentum vs. energy
- stationary source approximation
- relevance of the wave packets
- coherence

matters for

Oscillations of ``Mossbauer neutrinos''

In medium: oscillations at extreme conditions - high densities temperatures, magnetic fields, etc..

Neutrinos in neutrino gases: effects of the νν–scattering, collective, non-linear effects

Phenomenology

of the scenario

Solar neutrinos

Long baseline experiments

Atmospheric neutrinos

Supernova neutrinos

Cosmic neutrinos

Relic neutrinos

Reactor neutrinos

To large extend phenomenology of standard scenario has been elaborated; in some cases - in great details

Still some areas exist (cosmic, supernova neutrinos) where active research continues now

Few spots are not covered yet

Comments

Solar neutrinos

Comprehensive description of neutrino conversion; very precise analytic results

From experimental side - detection of
- the earth matter effect (day-night asymmetry, zenith angle dependence of signal);
- upturn of spectrum;
- N,O, pep- neutrinos
- pp-neutrinos (??)

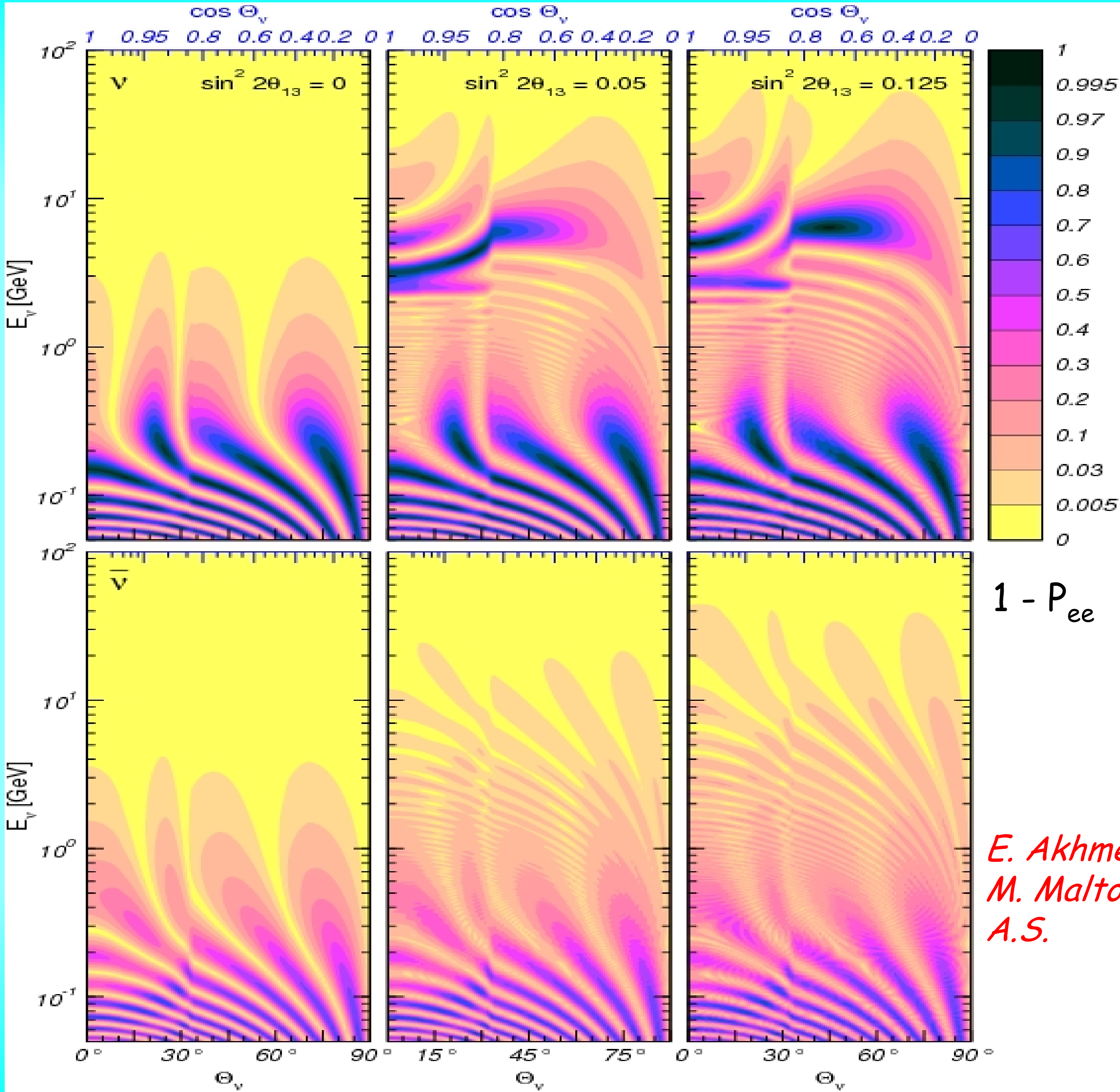
Atmospheric neutrinos

Comprehensive description of physical processes in terms of oscillograms of the Earth

Structures of oscillograms:
- collinearity condition
- generalized phase condition

CP- domains given by grids on magic lines and lines of the interference phase condition

Oscillograms of the Earth

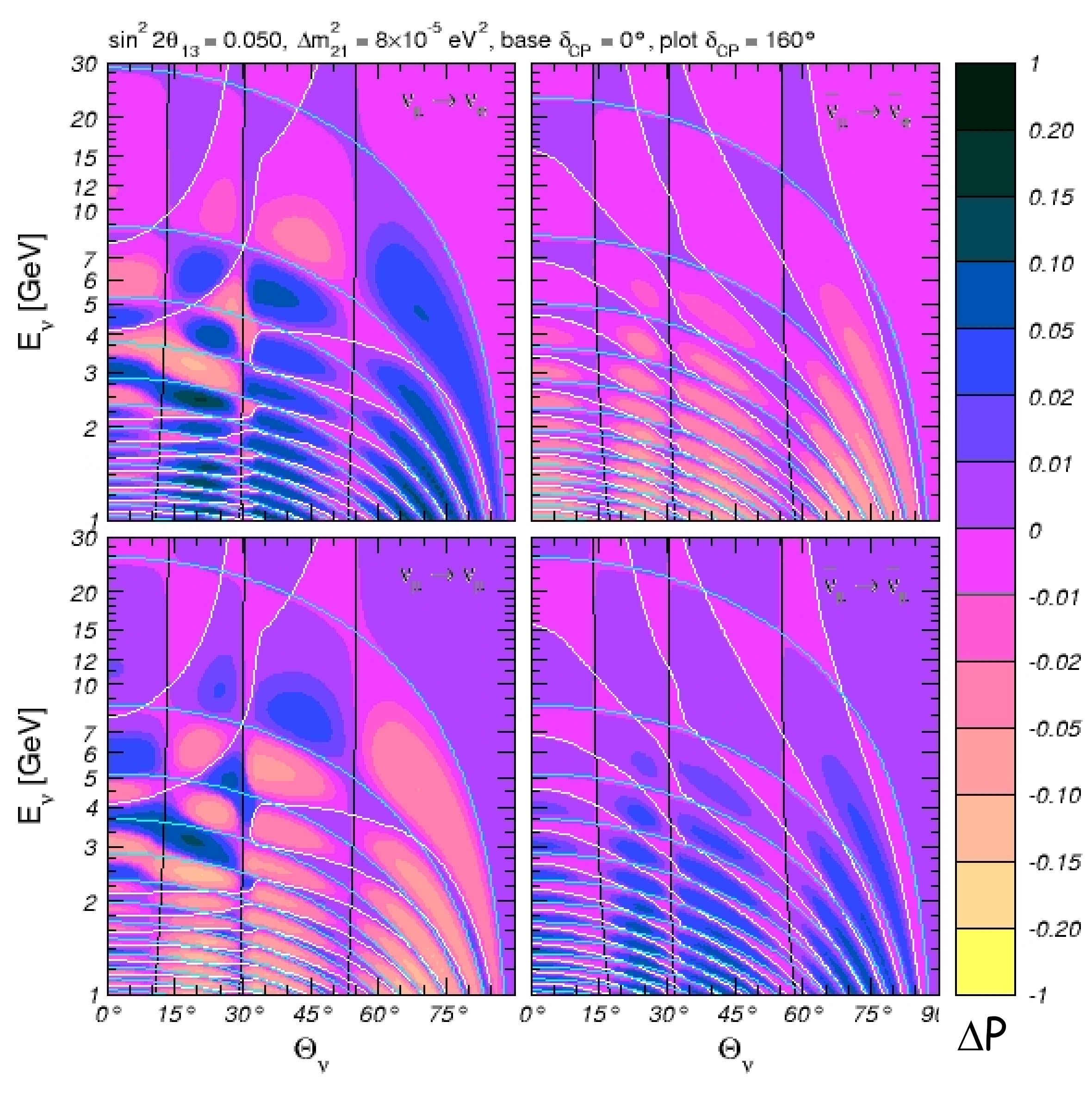


E. Akhmedov
M. Maltoni
A.S.

CP-violation domains

P(δ) – P(0)

formed by grids of magic lines and lines of interference phase



Supernova neutrinos

Further studies of collective effects:

can change whole picture of conversion

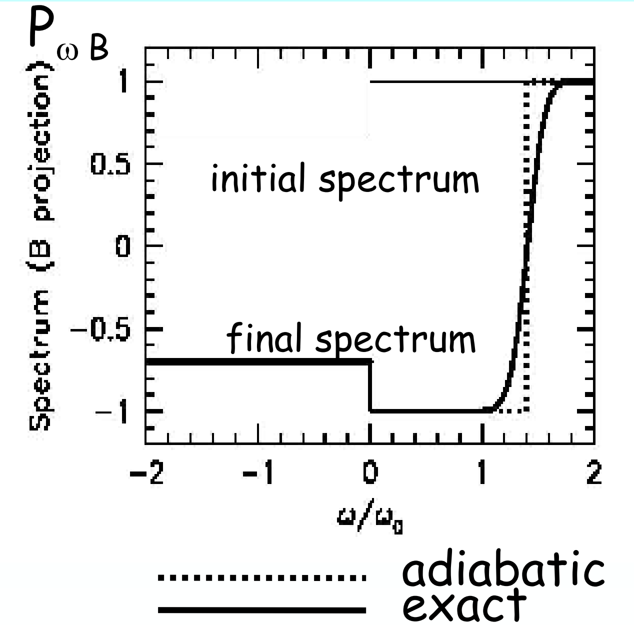
$\mu = \sqrt{2}\, G_F n_\nu$

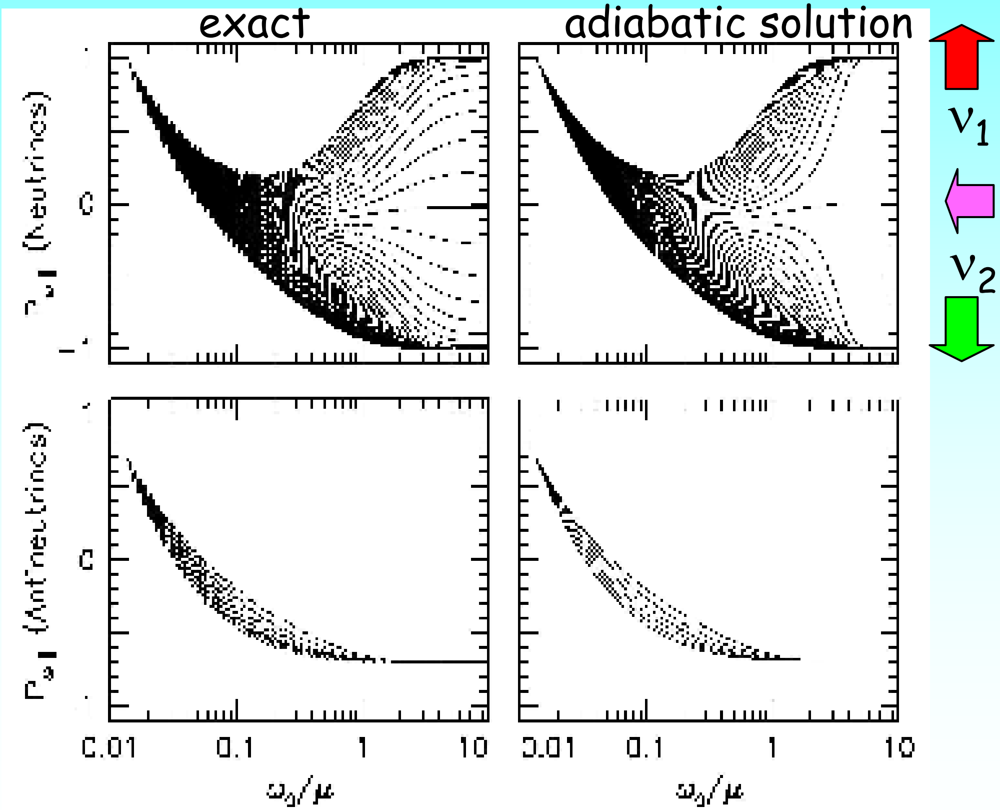
$\omega = \Delta m^2/2E$

Spectral splits (swapping)

H. Duan, G. Fuller, J. Carlson, Y. Z. Qian

G. G. Raffelt, A.S.





G. Raffelt, A.S.

Cosmic neutrinos

New level of studies

Sources:

AGN

GRBs

core-collapse supernovae

SN remnants

microquasars

blasars

Related to developments of γ-astronomy

$E \sim 1$ GeV - 10^4 TeV

Detailed computations of the neutrino yield (output) at different conditions

Propagation:

Vacuum oscillations

Conversion in matter of source

studies of various non-standard effects

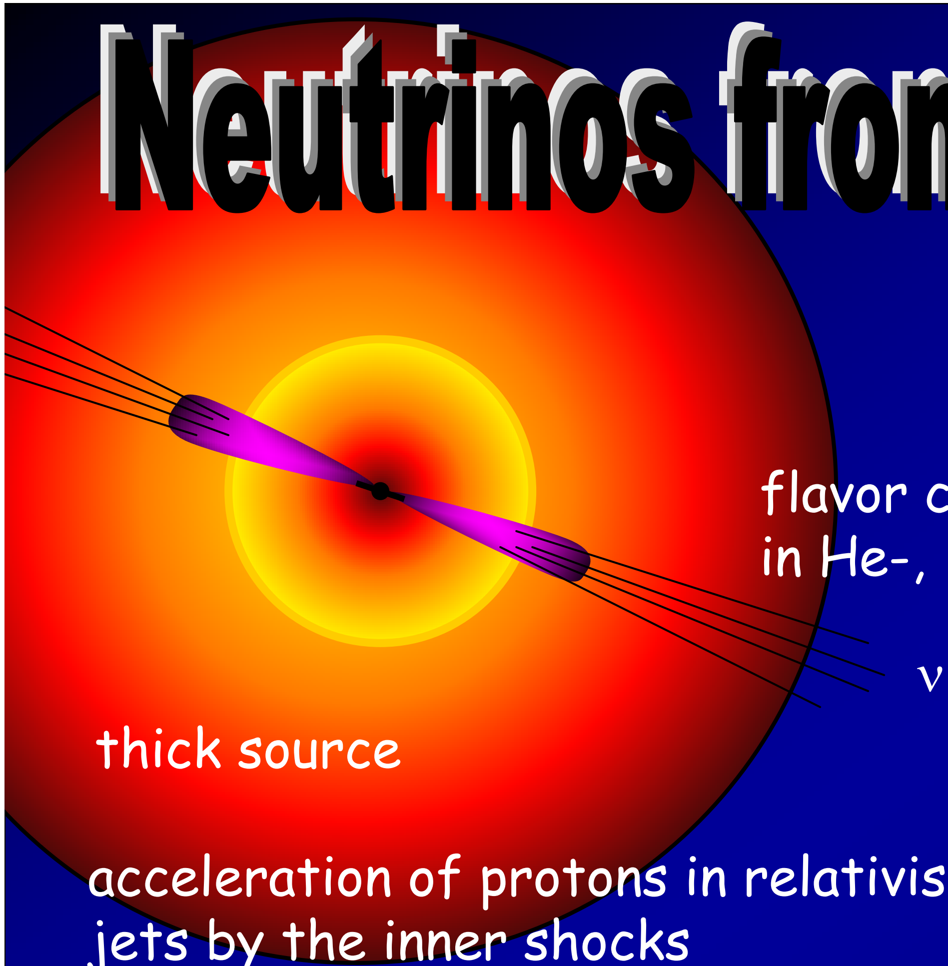
for maximal 2-3 mixing and 2 : 1 : 0 original ratio flavor equilibration:

1 : 1 : 1

deviations from 1 : 1 : 1

- ν production mechanism
- $\theta_{23} = \pi/4$

Neutrinos from astrophysical sources



flavor conversion
in He-, H- envelopes

thick source

acceleration of protons in relativistic jets by the inner shocks

pp -, pν - collisions → neutrinos

flavor conversion in outer layers
→ breaking of 1:1:1 flavor equilibration

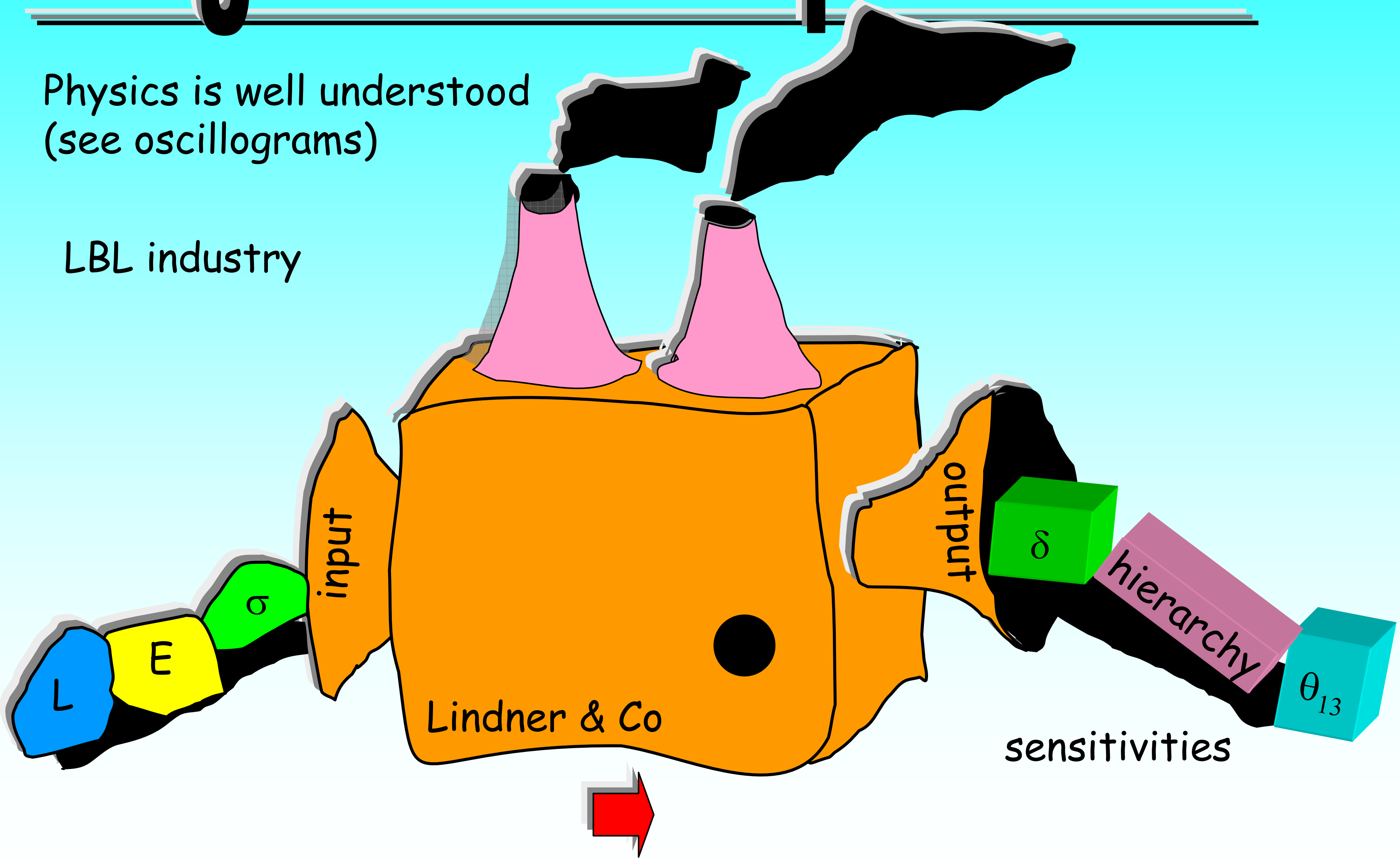
Measurements of deviation of 2-3 mixing from maximal

Sensitivity to 1-3 mixing, type of mass hierarchy, CP - phase

Long baseline experiments

Physics is well understood
(see oscillograms)

LBL industry



sensitivities

Masses and Mixing

Standard scenario

Right handed components of neutrinos exist

Smallness of mass is due to some mechanism, that involves the EW scale and probably some higher scale(s) of nature

In general:

$$m_\nu = m_{hard} + m_{soft}(E,n)$$

medium-dependent soft component

Bounds on m_{soft}

Neutrinos are Majorana particles?

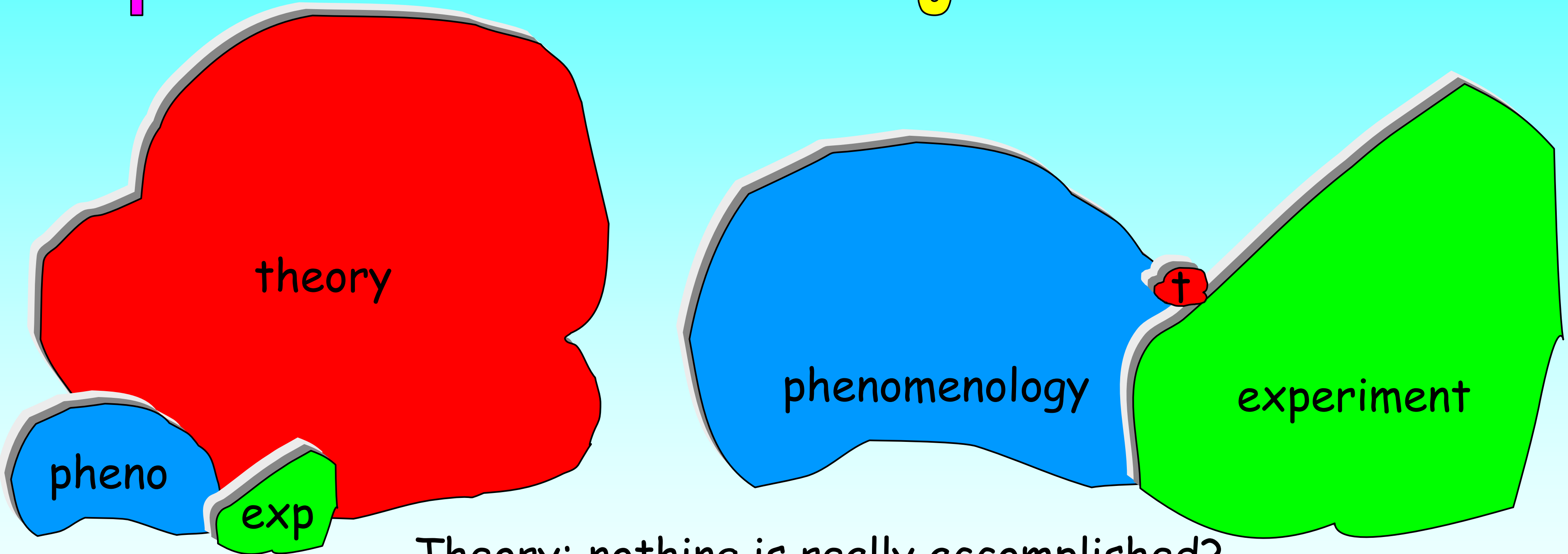
In the context of the see-saw mechanism: M_R(heaviest) ~ M_{GUT} is an interesting possibility

Difference of the quark and lepton mass spectra and mixing patterns is related to the smallness of neutrino mass

Where are we in understanding neutrino mass & mixing?

Theory of neutrino mass

Papers 2006 - 2008 **Program: nu-2008**



Theory: nothing is really accomplished?
No progress? Why? What should be done, measured?

Recall

we measure neutrino parameters
to uncover the underlying physics
to make on this basis new predictions,
to find applications

Whole the excitement was that neutrino mass and mixing are manifestations of physics beyond the standard model!

Dramatically, after many years and many trials the underlying physics hasn't been identified. Certain problems have been realized.

Nevertheless, we should further pursue this search, concentrating on how the progress can be achieved

Bottom-up

Tri-bimaximal mixing

With different implications:

Flavor symmetry

Extension to quarks ?

- subject of RGE
- no relation to masses?
- additional ambiguities (CP-phases)

Quark-Lepton complementarity

"bi-maximal - CKM"

QLC$_\nu$

$V_{CKM}{}^+ V_{bm}$

QLC$_l$

$V_{bm}{}^+ V_{CKM}$

Quark-lepton symmetry, GUT

structure which produces bi-maximal mixing - symmetry?

GST-approach mass-mixing

Gatto-Sartory-Tonin

The same principle as in quark sector

Large mixing is related to weak mass hierarchy of neutrinos

Disentangling possibilities

θ_{12} , θ_{13}

TBM

35.2°, 0

θ_{13}

QLC$_\nu$

35.4°, 9°

θ_{12} , θ_{13}

θ_{12}

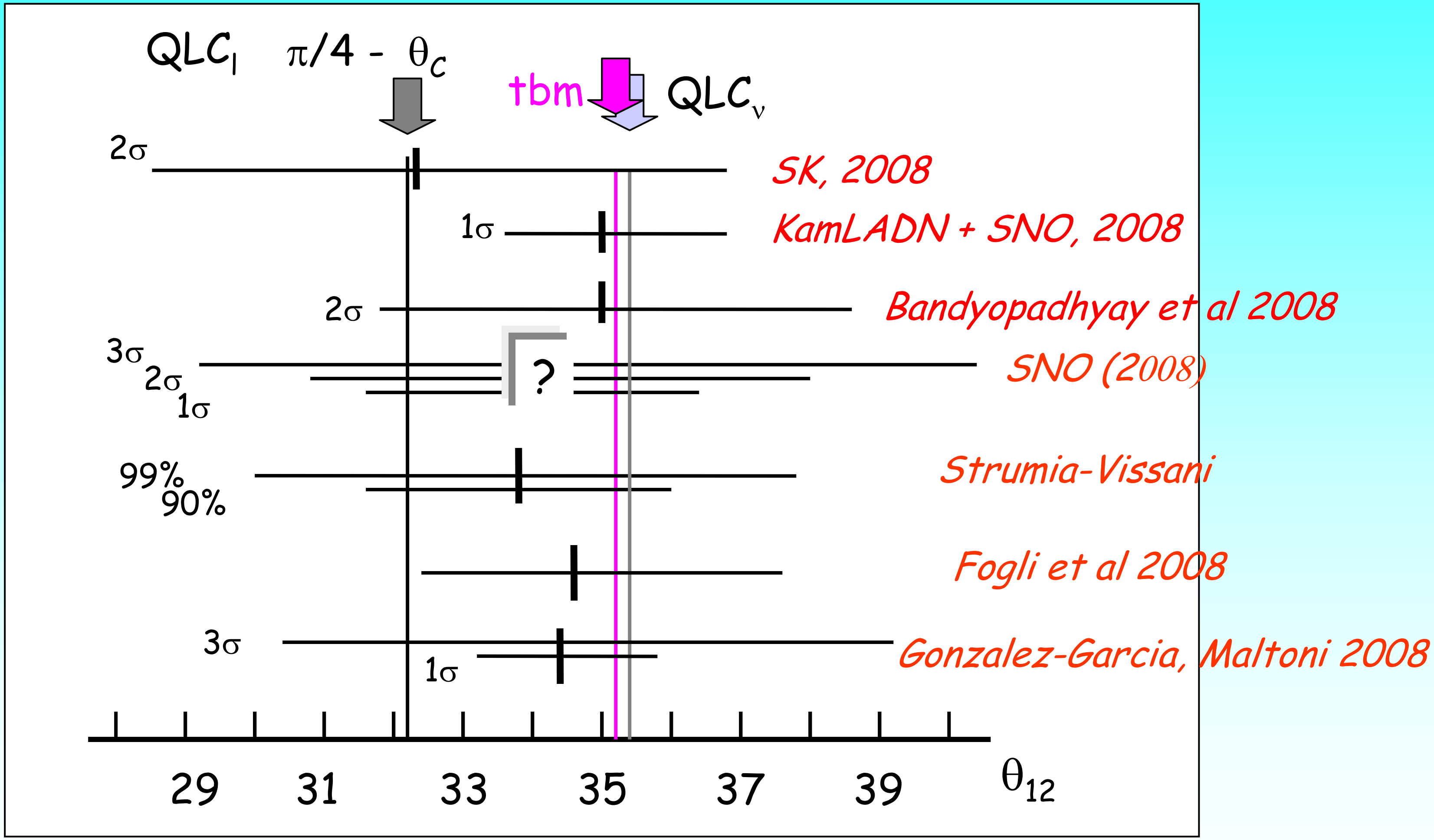
QLC$_l$

32.2°, 1.5°

TBM: 23-mixing
should be zero
or very small

1-2 mixing

Precision & benchmarks



$\theta_{12} + \theta_C \sim \pi/4$

$U_{QLC1} = U_C U_{bm}$

$U_{tbm} = U_{tm} U^m_{13}$

give almost same 12 mixing

Koide relation

Y. Koide, Lett. Nuov. Cim. 34 (1982), 201

$$\frac{m_e + m_\mu + m_\tau}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2} = 2/3$$

with accuracy 10^{-5}

all three families are involved:
no perturbation approach!

was obtained in attempt to explain

$$\tan\theta_C = \sqrt{3}\ \frac{\sqrt{m_\mu} - \sqrt{m_e}}{2\sqrt{m_\tau} - \sqrt{m_\mu} - \sqrt{m_e}}$$

Both relations can be reproduced if

$$m_i = m_0 (z_i + z_0)^2$$

$$\Sigma_i z_i = 0, \quad z_0 = \sqrt{\Sigma_i z_i^2 / 3}$$

C A Brannen

Neutrinos, hierarchical spectrum

Non-abelian flavor symmetry, VEV alignment

Related to TBM?

Flavor symmetries

Real symmetry

Flavor features of various symmetry groups have been explored

Discrete groups:

A_4 (subg. SO_3) - many studies
T_7 (Frobenius) (subg. SU_3)
Looks promising

Deriving the group from observations
S C Lam:

TBM → S_4 minimal symmetry

Effective symmetries:

- No symmetry (or some other symmetry) at the fundamental level.
- Required symmetry appears at the effective level after decoupling of heavy degrees of freedom

Partially realized in some models

``See-saw symmetry"

Along with this line:
``Symmetries from mass hierarchies"
Ferretti , S. King, A. Romanino,

Real or accidental?

Tri-bimaximal mixing

Q-L-complementarity

Very small 1-3 mixing

Maximal 2-3 mixing

Koide relation

Real:
immediate ``one step"

Accidental: interplay
of different independent
factors contributions

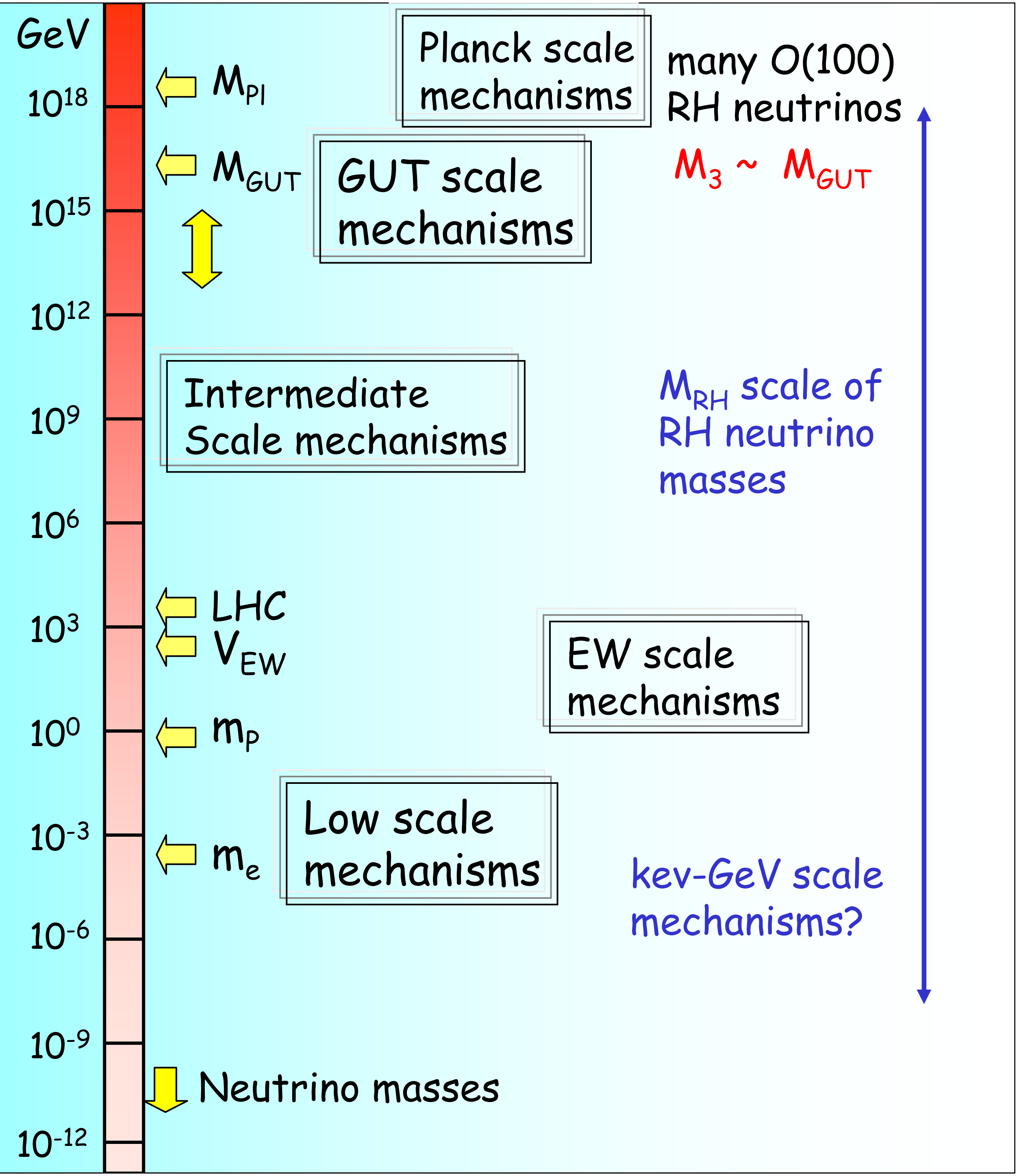
Discovery of degenerate neutrino mass spectrum would be
convincing evidence of existence of symmetry

KATRIN

Heidelberg-Moscow

Degenerate spectrum and TBM are not related ?

Energy scales of new physics



Physics behind neutrino masses is not identified

Flavor & GUT

Generic problem:

GUT's: unification of quarks and leptons

difference of mass and mixing pattern

difference of flavor properties

Relate this difference to spontaneous breaking of GUT symmetry

SO(10)

126_H

Non-renormalizable operators

Singlet fermions

flavons

C Hagedorn
M. Schmidt A.S.

SO(10) + singlets + discrete flavor symmetries

→

Geometrical hierarchy of the up quark masses

relates

Nearly maximal 2-3 mixing

Beyond the standard scenario

Two aspects:

Tests of the standard scenario

Searches for new physics

Classifying possibilities

Neutrino anomalies

were driving force of the developments for more than 40 years

related to explanation of neutrino masses

New physics motivated by other fields

Various extensions of the standard model: SUSY, LR-symmetry, GUT extraD

Recall, 10 - 20 years ago ``standard'' would be:

- zero mass,
- zero mixing...

Unmotivated

Anomalies: unresolved and new

Seeds of new developments?

name:	feature:	possible interpretation
LSND	excess of e^+-events	see separate slide
MiniBooNE	excess of events at low energies	
NuTeV	value of sin θ_W	
Homestake	low signal, tension with other data	mixing with very light sterile neutrino
Unnamed	time variations of solar neutrino signals?	- neutrino magnetic moment, - periodicity of energy release
SN 1987A	angular, time distributions LSD signal	Astrophysics?
Z^0 -width	$N_\nu < 3$	Hadron physics?
New GSI	modulation of exponential decay	Nothing to do with neutrinos?

LSND after MiniBooNE

or MiniBooNE after LSND

True or fake… triggered a number of developments

Two sterile neutrinos with CP? *M. Maltoni, T. Schwetz*

(Exotics)^2

Light vector boson + 3 sterile nu *A. Nelson, J Walsh*

CPT violation + sterile neutrinos *V. Barger, D. Marfatia, K. Whisnant*

Soft decoherence *Y. Farzan, T. Schwetz, A.S.*

Something very exotic not connected to known physics processes

= Mechanism X
or LSND-effect

⇒ Reconstruct from data its L and E dependence,

checks of consistency

New Physics

NSI

Non-Standard
Interactions

Vector,
U(1)'

Tensor

Scalar

Light
particles

Heavy

New
neutrino
states

Sterile neutrinos

New
dynamics

Violation
Of fundamental
Symmetries: CPT
Lorentz invariance
Pauli principle

Unparticle
physics

Non-standard interactions

Motivation: new physics
at the EW and terascale;
various extensions of SM
Z', SUSY, KK, light particles

Rich phenomenology
- propagation
- detections

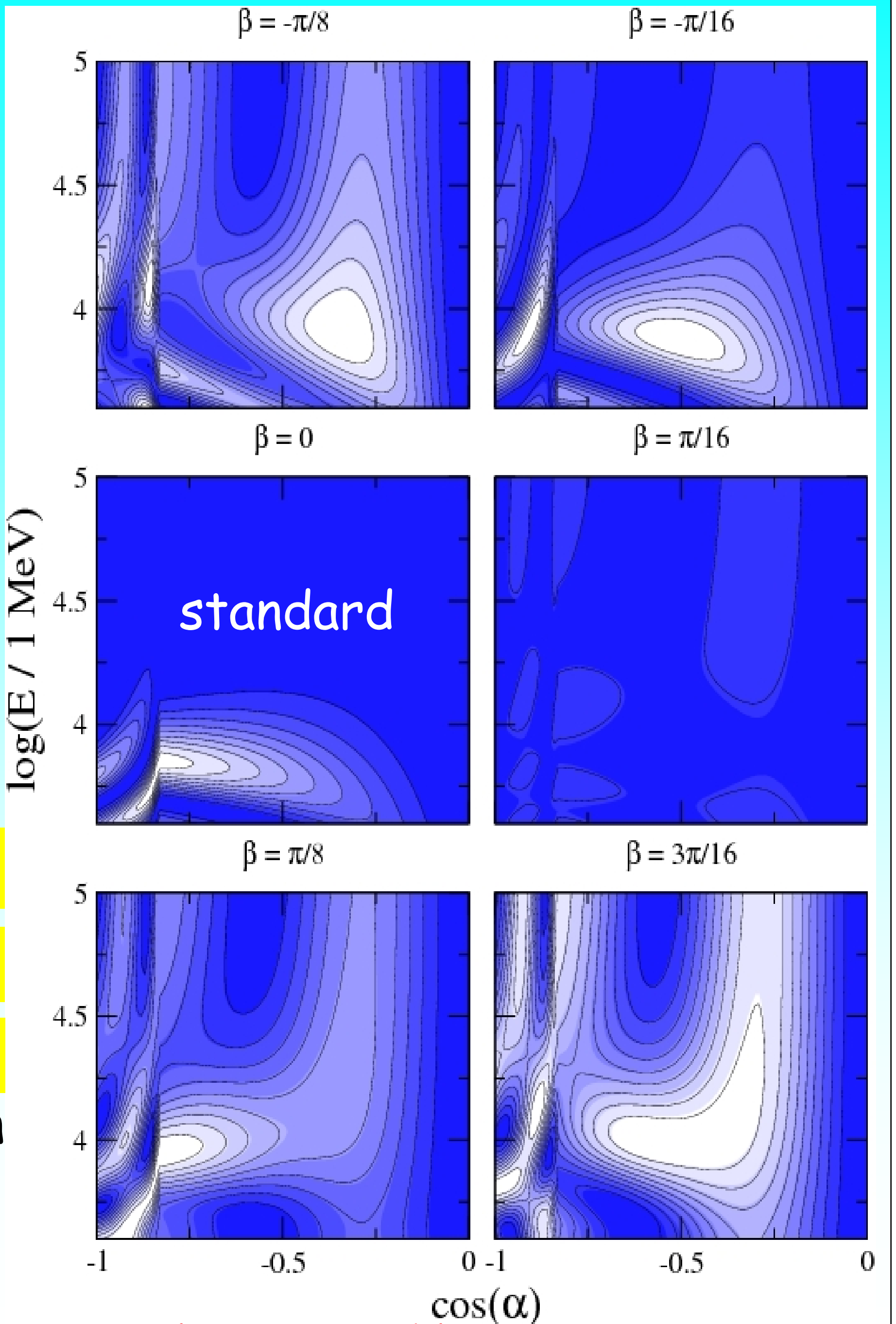
High energies where usual mixing is suppressed...

P_{ee}

θ_{13} = 8°

$\varepsilon_{e\tau}$ ~ - 0.5 sin2β

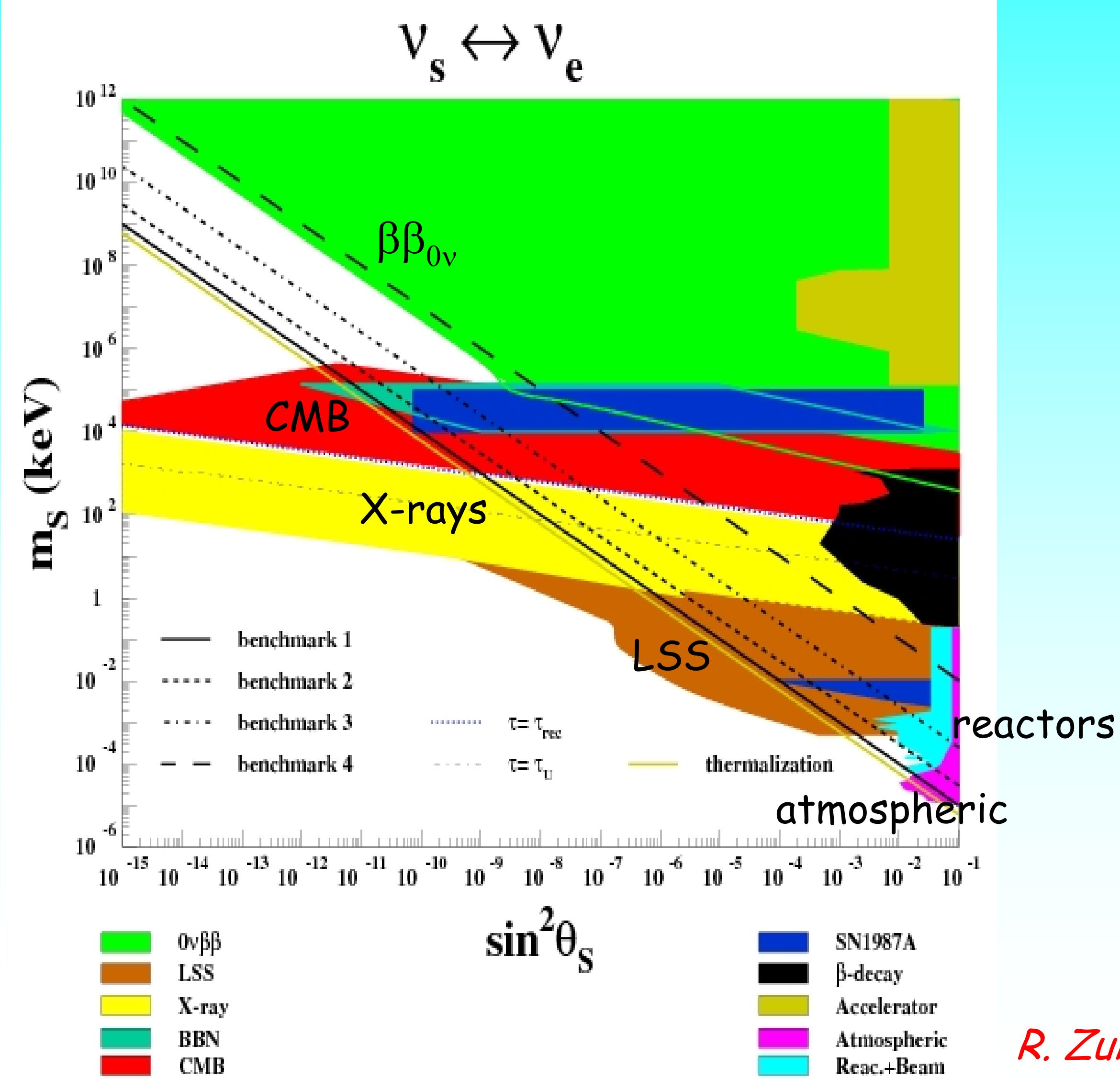
white: strong transition



M. Blennow, T. Ohlsson, 0805.2301

Checks at LHC,
Rare processes with L-violation

Sterile Neutrinos



Contours of constant induced mass and bounds

thermalization line:
above if S are in equilibrium

For benchmark parameters S were thermalized

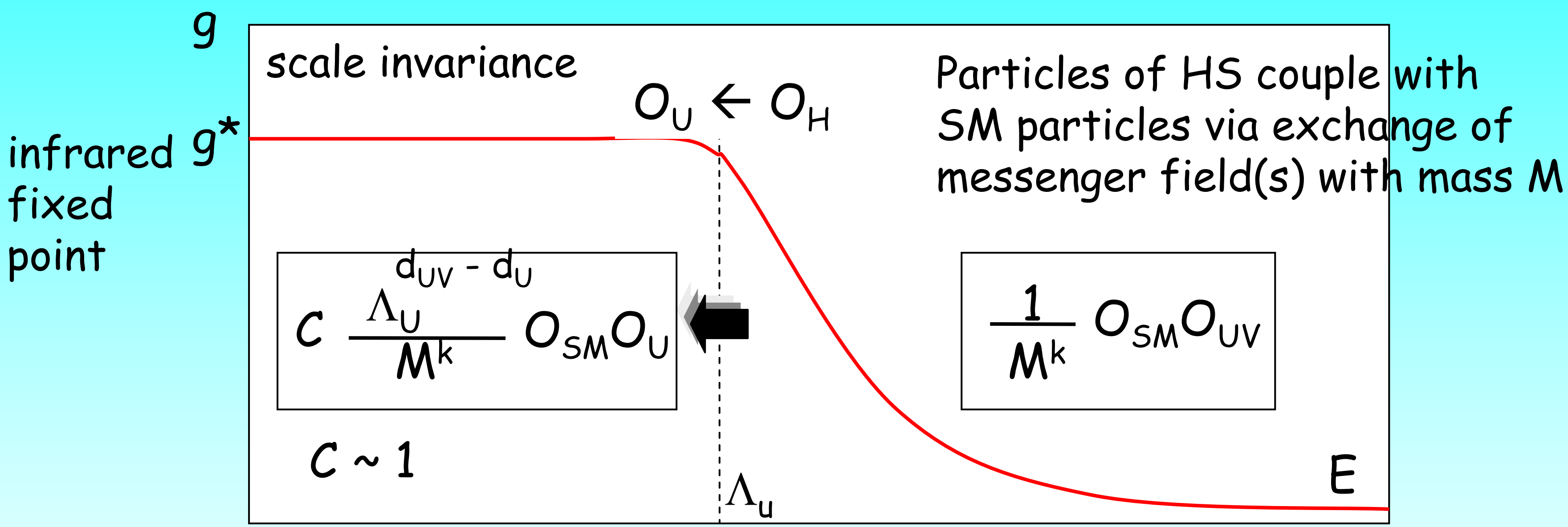
Bounds - in non-equilibrium region

R. Zukanovic-Funchal, A.S.

Unparticles

H. Georgi

Hidden sector (HS) e.g., gauge theory with fermions and coupling g



If $g^* \gg 1 \rightarrow$ appearance of composite (confined) states of the HS particles (described by operators O_U)

hadrons ← quarks

N. Krasnikov
M. A. Stepanov

Key difference:

Scale invariance → continuous mass spectrum of confined states, Each has infinitesimal coupling with SM particles. Integral is finite

Individual (mass) modes: negligible effect

Unparticle effects

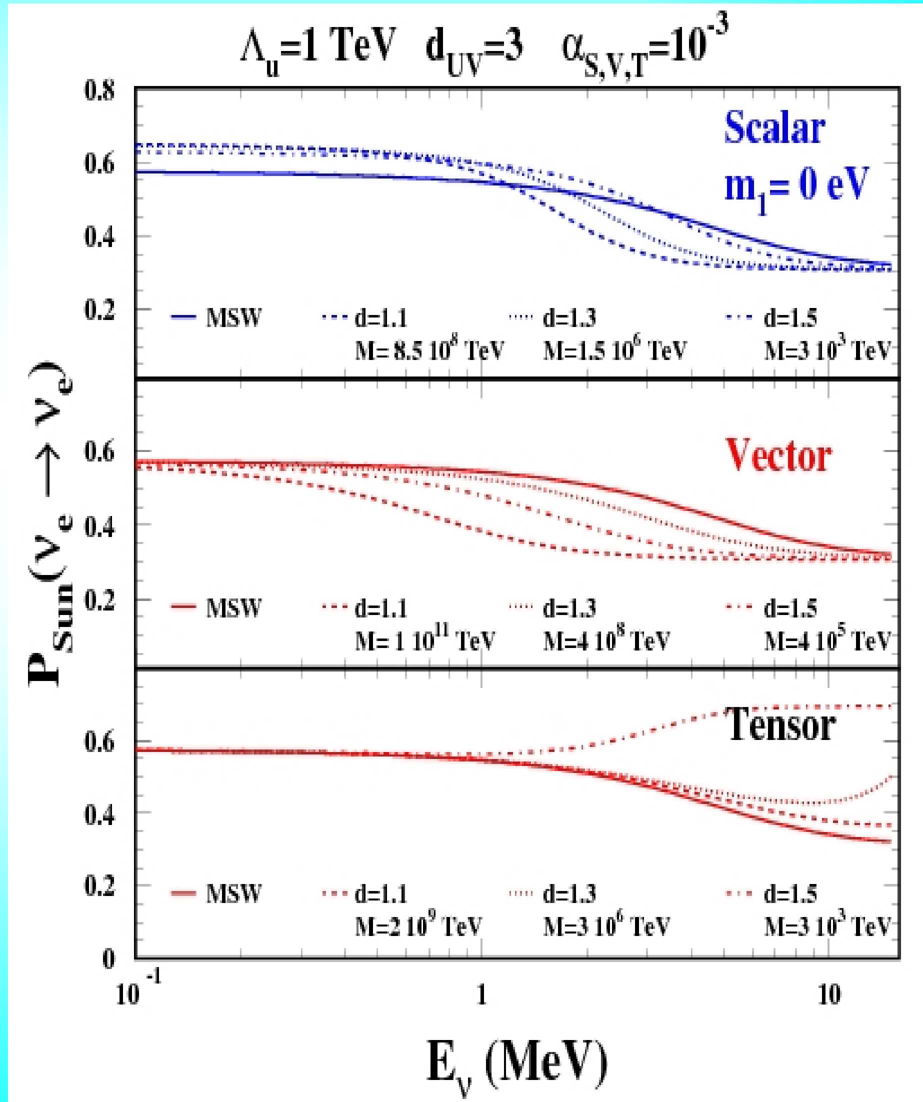
Effects in solar neutrinos

Neutrino decay: $\nu_i \rightarrow \nu_j\, U$

L. Anchordoqui, H. Goldberg

Unparticle exchange:
modify mater potential
and effective neutrino mass
→ modify survival probability

M.C. Gonzalez-Garcia,
P.C. de Holanda,
R. Zukanovich-Funchal



M – mass of messenger

d_H - dimension of operator in hidden sector,

d – dimension of unparticle operator

Λ_U - infrared fixed point

Future which we know

Accomplish reconstruction of the neutrino mass and mixing spectrum

- 1-3 mixing
- deviation of 2-3 mixing from maximal
- CP-phase
- m_{ee}, nature of neutrinos
- absolute scale
- Majorana phases

The program emerged more that 10 years ago

well motivated and elaborated

Reconstruction of neutrino mass matrix

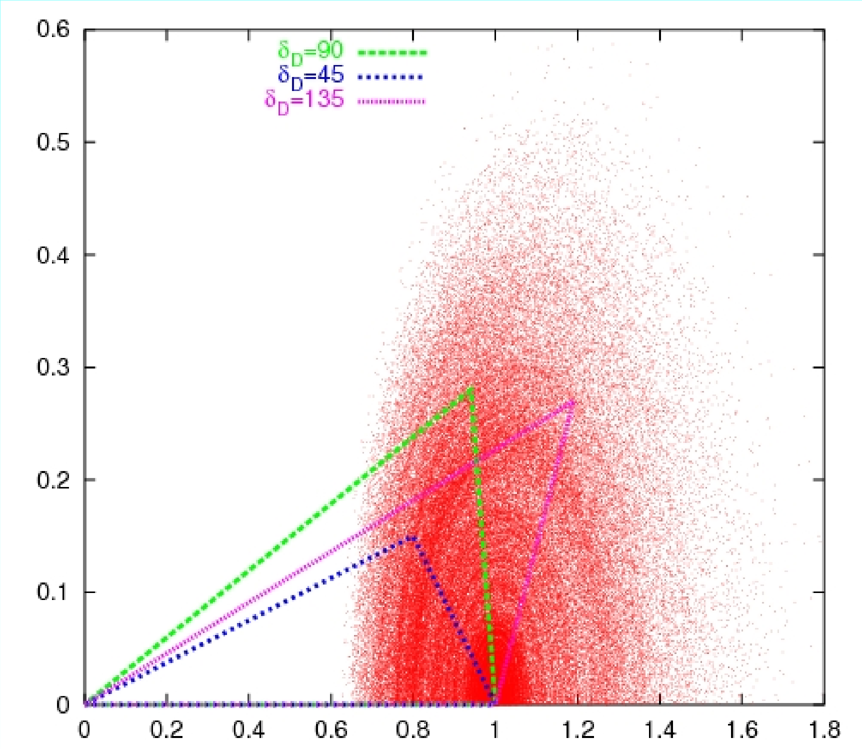
May not reconstruct completely

20 - 30 years?

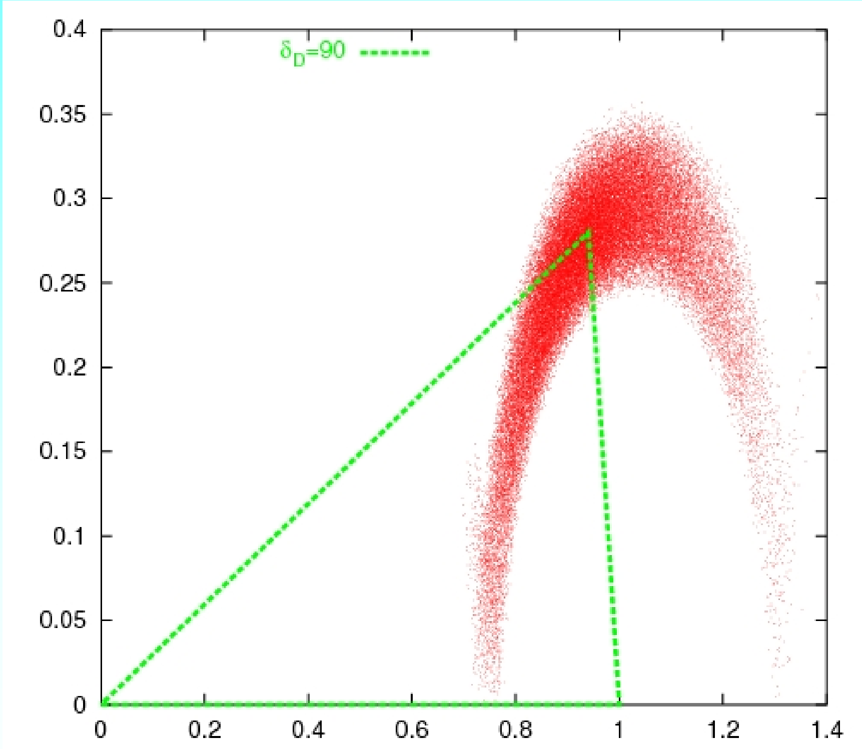
Leptonic unitarity triangle

$e\mu$ - triangle $\sin\theta_{13} = 0.15$

today



in future

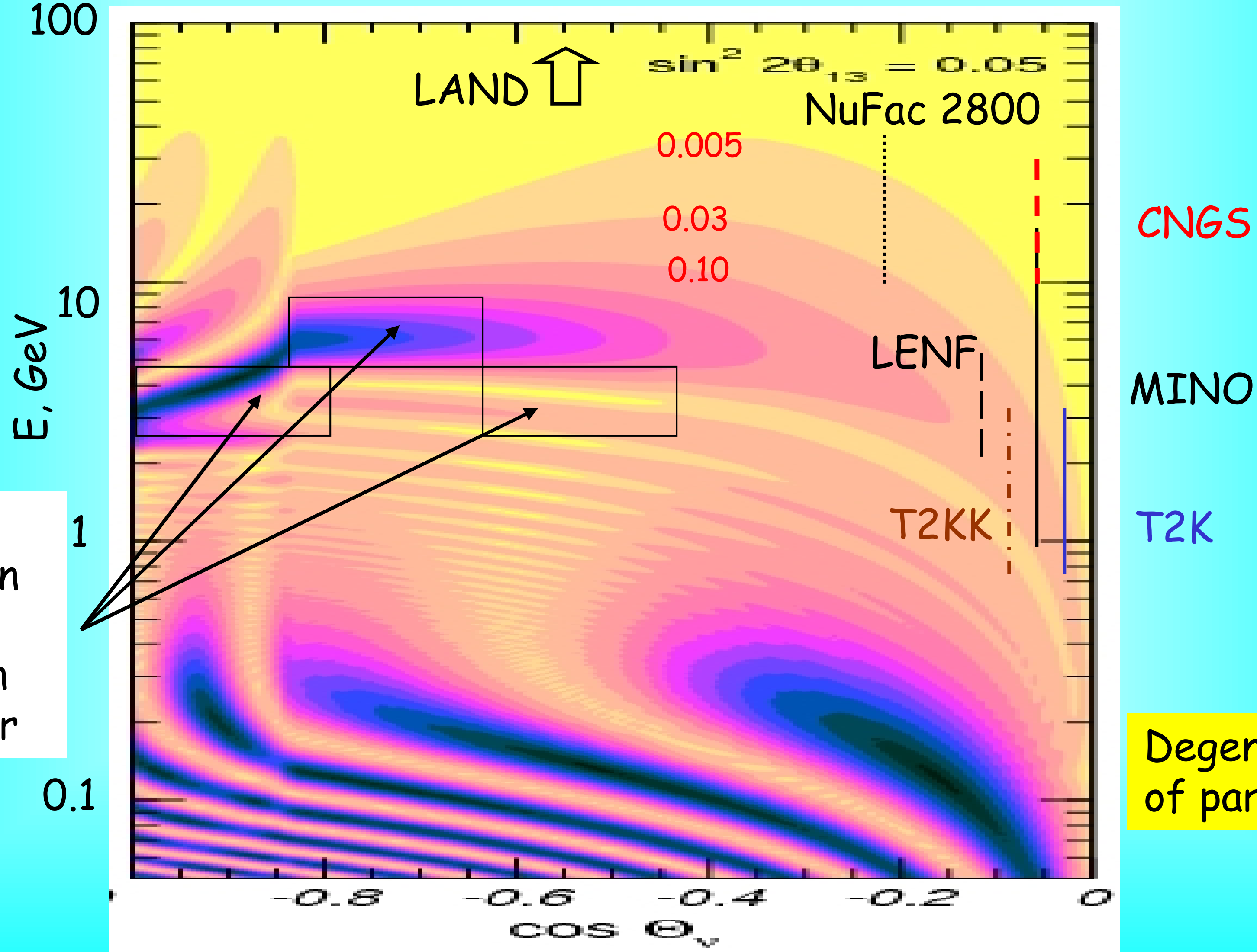


- illustration
- method to measure δ, test of unitarity?

Y. Farzan

Another approach?

Large atmospheric neutrino detectors



~ 2000 events in Multi-megaton detector

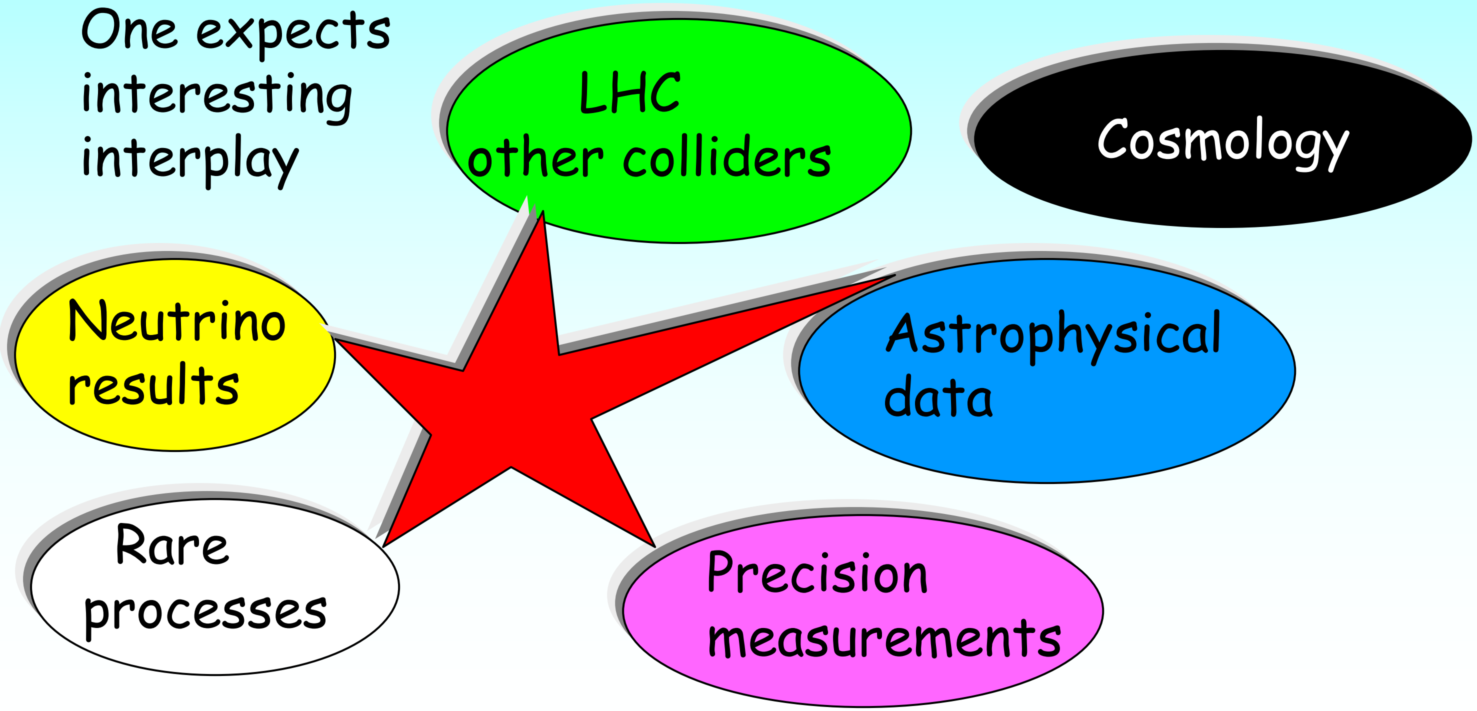
Degeneracy of parameters

Searches for new physics beyond standard scenario

improving bounds ....

Precision measurements in neutrino physics

One expects interesting interplay



Detection of neutrino burst from Galactic supernova

Eventually...

May have very strong impact on
Neutrino physics,
Astrophysics
Particle physics

Plausible: we discover something completely new.

Shed some light on
- explosion mechanism
- neutrino propagation and properties
- theory of conversion
- nucleosynthesis

Cosmic neutrinos

Searches, measurements of ν–fluxes

Further study of
$\nu - \gamma$ connection.
Implication of
EM radiation data

New developments related
to establishing the GZK cut-off
and evidences of AGN
as sources of the Cosmic rays

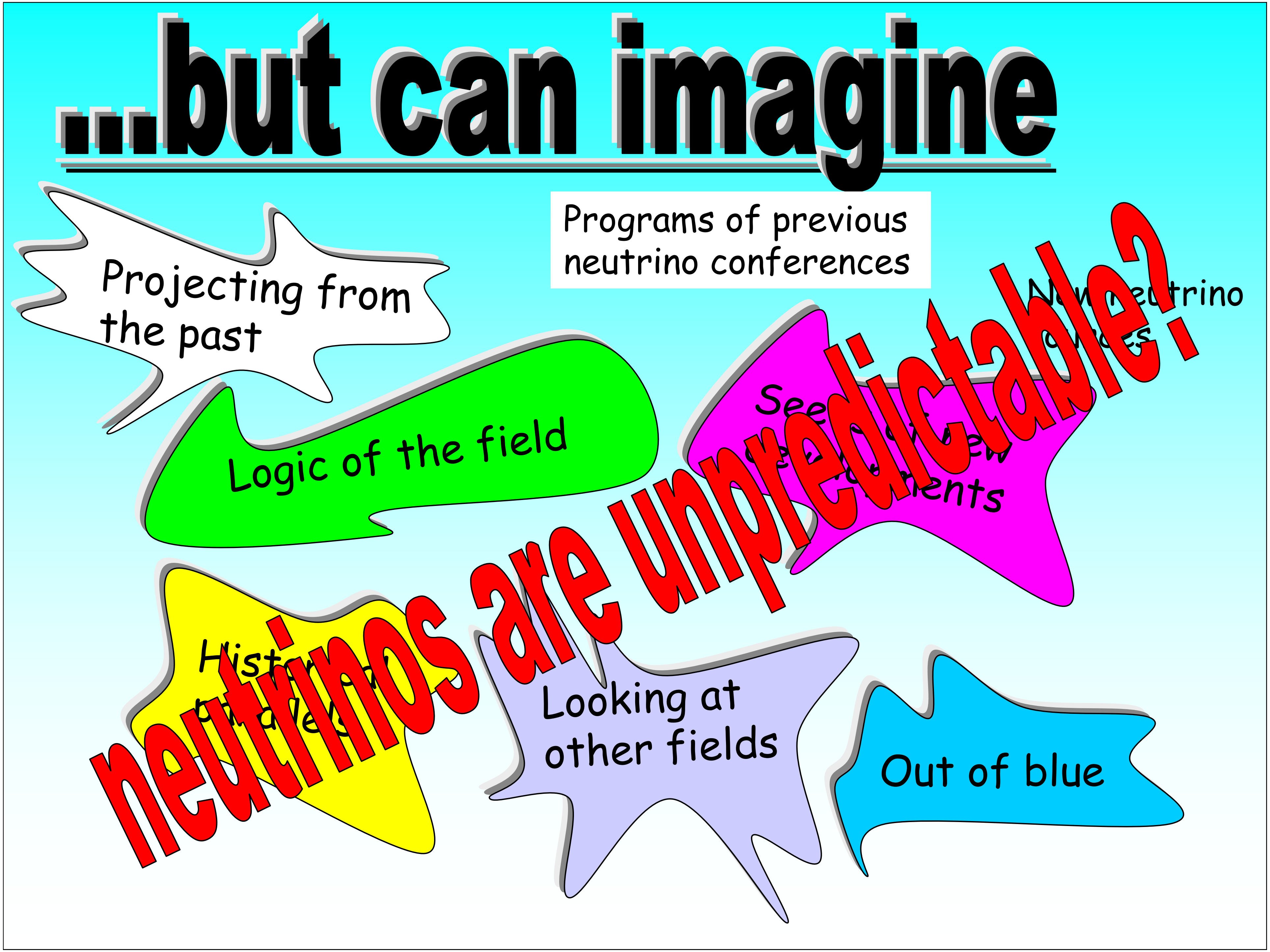
Cosmogenic,
GZK- neutrinos

Astrophysics

Determination of
neutrino parameters

Future which we don't know

Supposed to be prophetic?
- According to citation index – 45 max



...but can imagine
Programs of previous neutrino conferences
Projecting from the past
Logic of the field
Looking at other fields
Out of blue
neutrinos are unpredictable?

Neutrinos & LHC

Expectations range from

Identification of the mechanism of neutrino mass generation

e.g. if the Higgs triplet with terascale mass and
small VEV generates neutrino mass and mixing

to

Practically nothing

with conclusion that some EW scale mechanisms
with certain values of parameters are excluded

New experimental techniques

β-beams

Neutrino factories with rotating (changing direction) beams

New neutrino sources

Table-top experiments with sources

Radioactive nuclei
Metastable atoms
for neutrino detection

Mossbauer effect

Coherence

Detection of very weak signals

Multi-Megaton detectors

with flavor and charge identification
low energy threshold

New methods of decrease of backgrounds

superconductivity
Cryogenic detectors

Higher precision – new physics
open new horizons

Toward the neutrino technologies

some proposed long time ago
now less speculative
now we know much more

not unique, multiple use

Monitoring of nuclear reactors

Tomography of the Earth

- absorption
- oscilltion

Geo-neutrinos

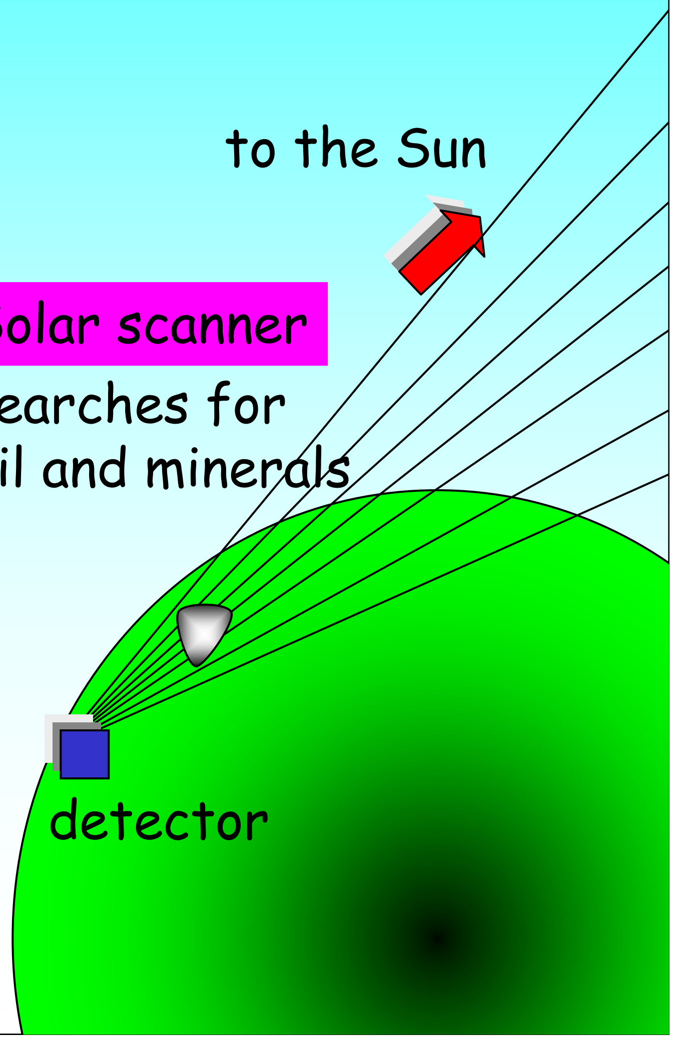
Mossbauer effect for neutrinos

Neutrino as a probe...

Neutrino communication systems
Galactic communication

Solar scanner

searches for
oil and minerals



J. Learnd,
S. Pakvasa
A. Zee

Neutrino structure of the Universe

Some work has already been done

Clumping of neutrinos depending on their masses

Neutrino halos, neutrino stars

Possible new interactions
accelerons

→ Neutrino condensates

Superfluidity

J. I Kapusta
J R Bhatt
U. Sarkar

Detection of relic neutrinos

Using metastable atoms
and nuclei

M. Yoshimura
P. Vogel et al

Summary

Neutrino physics is in the transition phase

Substantial territory is already ``captured''
which can be described as
the standard neutrino scenario

Tests of the standard scenario and searches
for ``physics beyond'' are the main motivations
for further studies

Precision measurement and exploration
of extreme conditions (energies, densities,
distances) will open new horizons

and what emerges?

Unclear implications of results to fundamental theory
- origin of neutrino mass and mixing
- existence of flavor symmetries, unification etc.

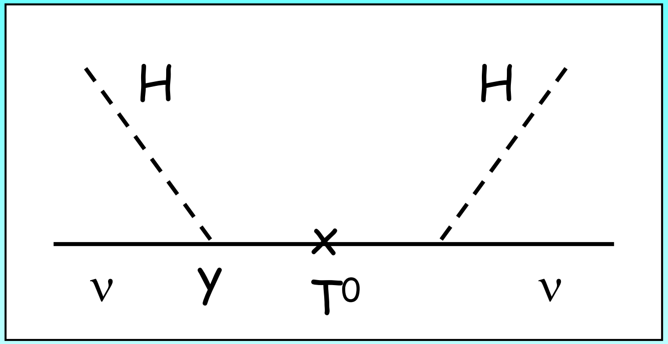
The question what should be done to have progress in understanding neutrino mass and mixing is already and will be a driving force of future developments

LHC and other HE experiments may clarify the situation

In spite of these problems we can start to think seriously about applications of neutrinos and neutrino technologies

RH neutrinos at LHC

- Type III seesaw:



S

SU(2) triplet:

$$T = \begin{pmatrix} T^+ \\ T^0 \\ T^- \end{pmatrix}$$

$y \sim 10^{-6}$

$M_T \sim 100$ GeV

B. Bajc
G. Senjanovic
M. Nemevsek
P. Filiviez-Perez

- In SU(5): 24_F T, S

$$y\, \overline{5}_F\, 24_F\, 5_H + y'/M\, \overline{5}_F\, 24_F\, 24_H\, 5_H$$

Type I + Type III
one usual neutrino is mass less

- **LHC:** EW production: $W^{+*} \rightarrow T^+\ T^0$, $Z^* \rightarrow T^0\, T^0$

Decay: $T^0 \rightarrow W\, l$, $T^0 \rightarrow Z\, \nu$, $T^0 \rightarrow T^+\, l^-\, \nu$

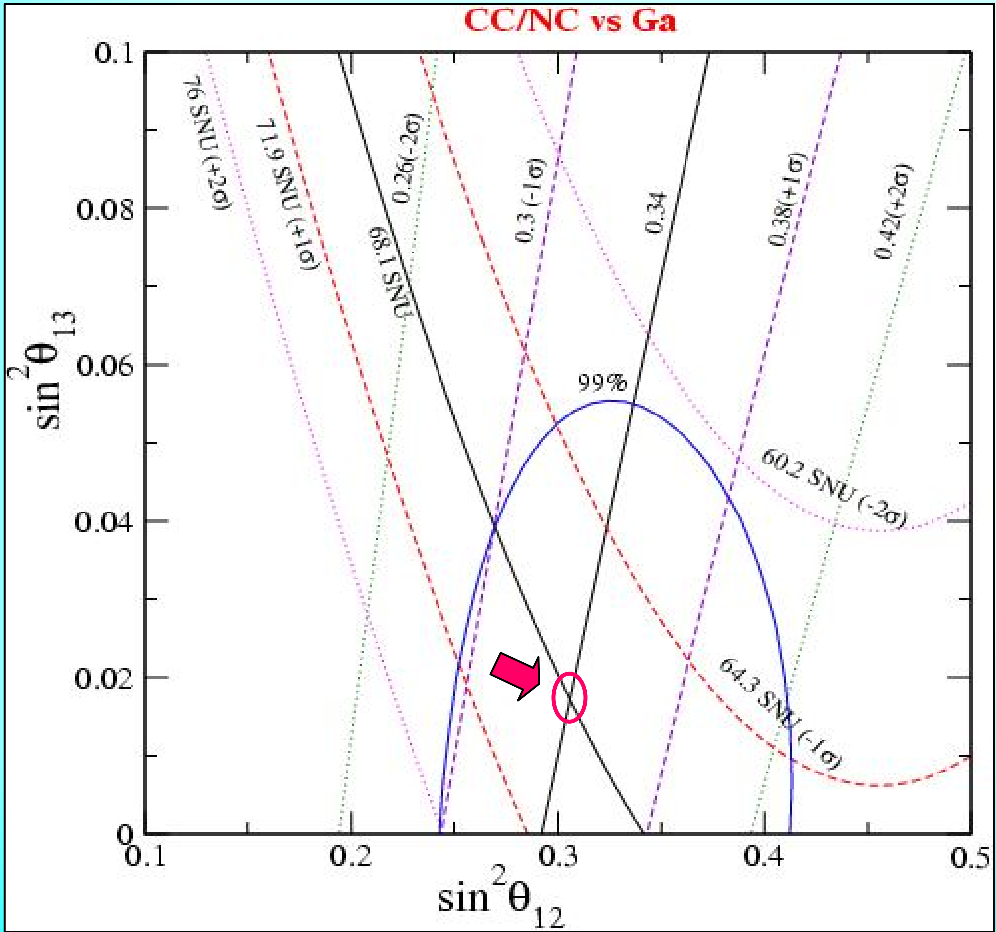
$\tau \sim 10^{-16} - 10^{-13}$ sec

$\Gamma \sim (\text{mixing})^2$

Theta 1-3

Solar neutrinos: degeneracy of 1-2 and 1-3 mixing

S. Goswami, A.S.



$\sin^2\theta_{13}$ = 0.017+/- 0.26

The best scenario

Minimal number of assumptions:

Assumption 1: $\cos^2\theta_{13} = 1$

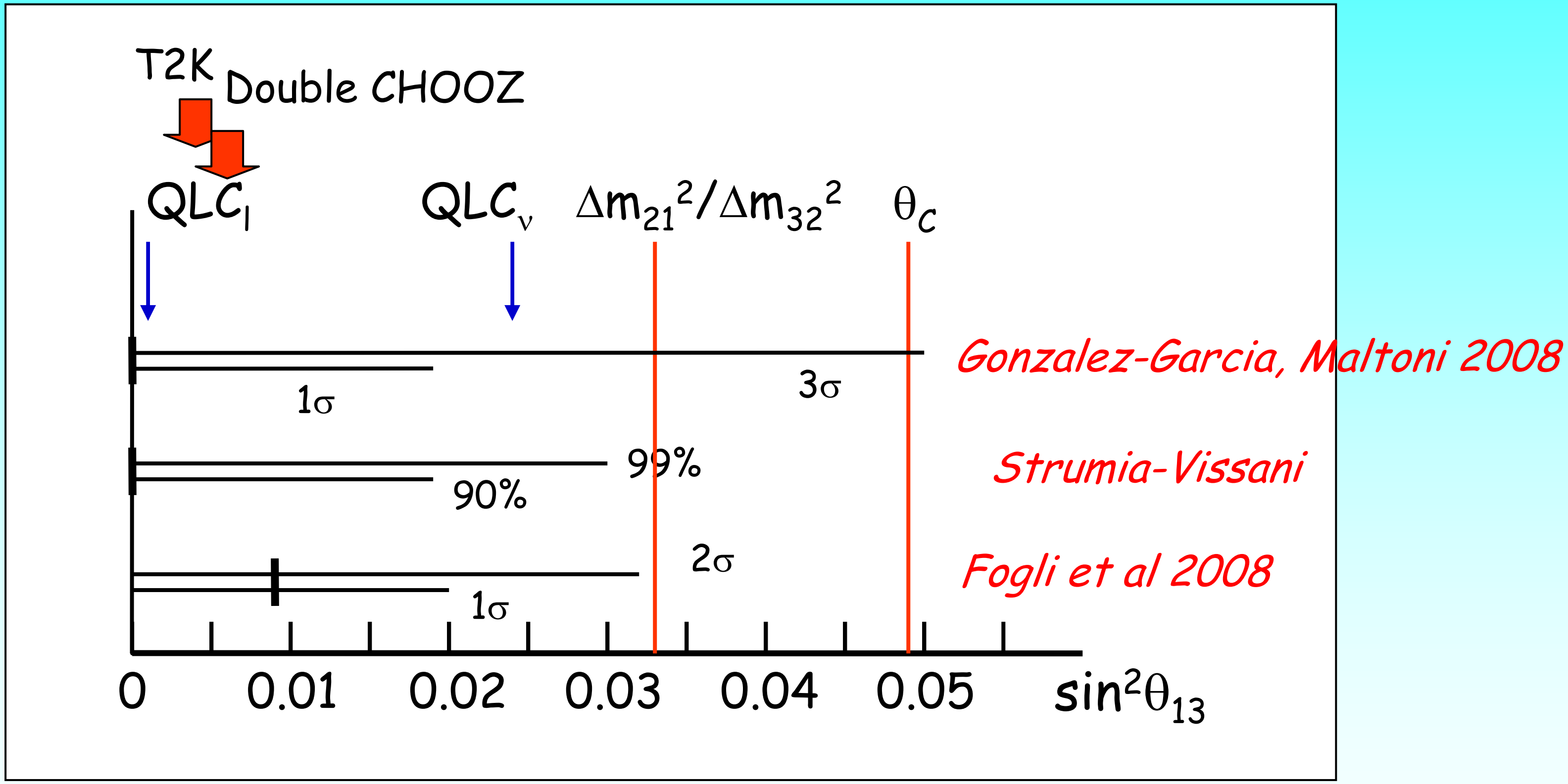
Assumption 2: $1/\sin^2\theta_{23} = 2$

Assumption 3: $1/\sin^2\theta_{12} = 3$

Plus possible small corrections…

Any model with smaller number of assumptions?

1-3 mixing

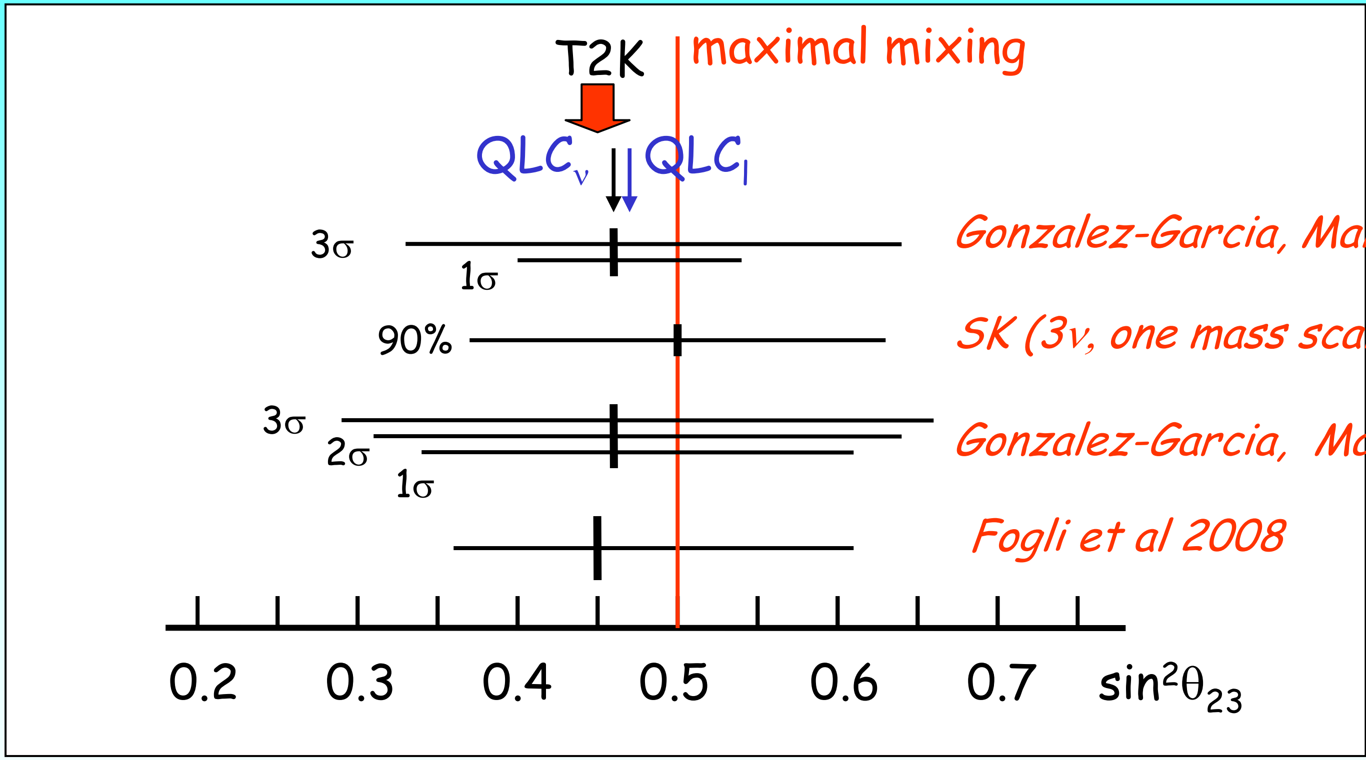


* Non-zero central value (Fogli, et al): Atmospheric neutrinos, SK spectrum of multi-GeV e-like events

* MINOS lead to stronger the bound on 1-3 mixing (G-G, M.)

2-3 mixing

SK: $\sin^2 2\theta_{23} > 0.93$, 90% C.L.



* in agreement with maximal, though all complete 3ν - analyses show shift
* shift of the bfp from maximal is small
* still large deviation is allowed: $(0.5 - \sin^2\theta_{23})/\sin\theta_{23} \sim 40\%$ 2σ

Resume

No unique and convincing explanation of neutrino mass has been found

We are still in the explorative phase

There is no simple ``one step" explanation/solution
large number of assumptions

Inclusion of quark sector usually requires further complication of models

Grand unification?

Perturbation approach:
do not try to explain everything at once

Lowest order (symmetry)

Perturbations may have no symmetry or different symmetry

Ambiguity to identify what is zero order