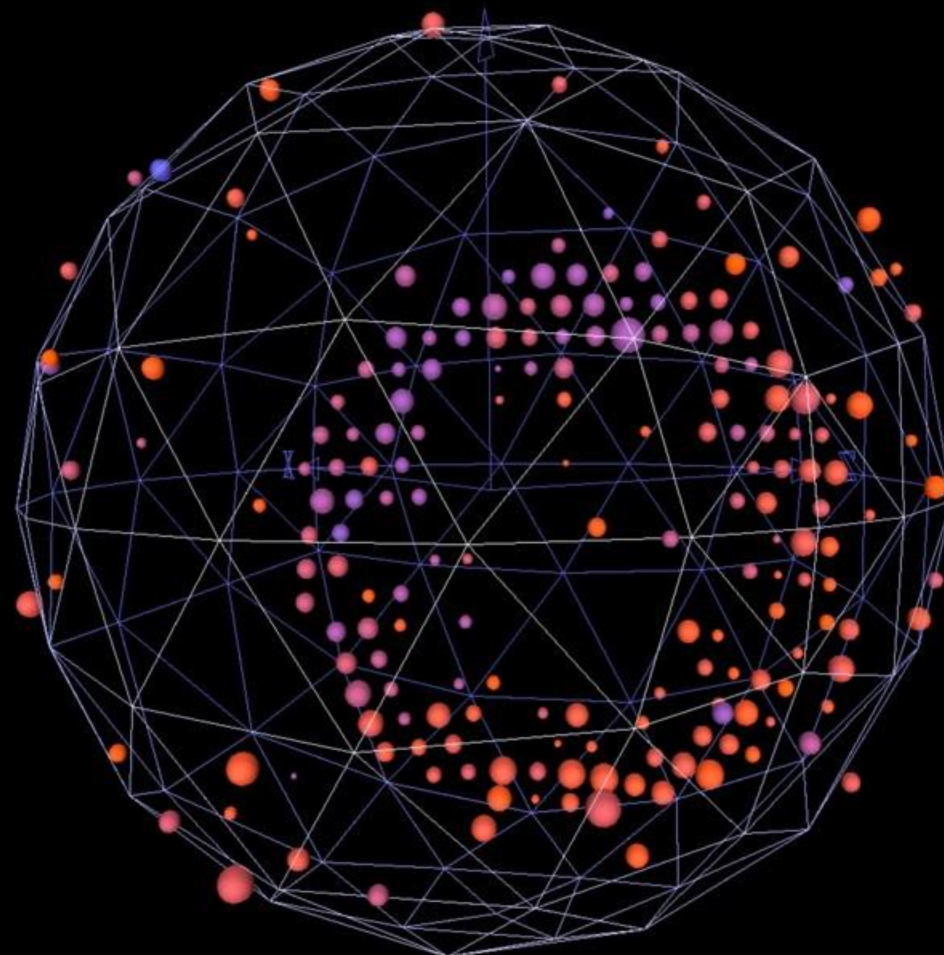
Lepton mixing from the Hidden sector



A. Yu. Smirnov

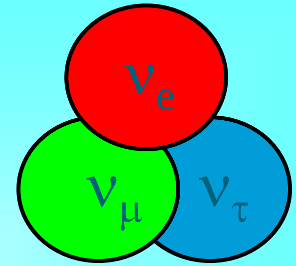
Max-Planck Institute for Nuclear Physics, Heidelberg, Germany

Heidelberg University , May21 , 2015

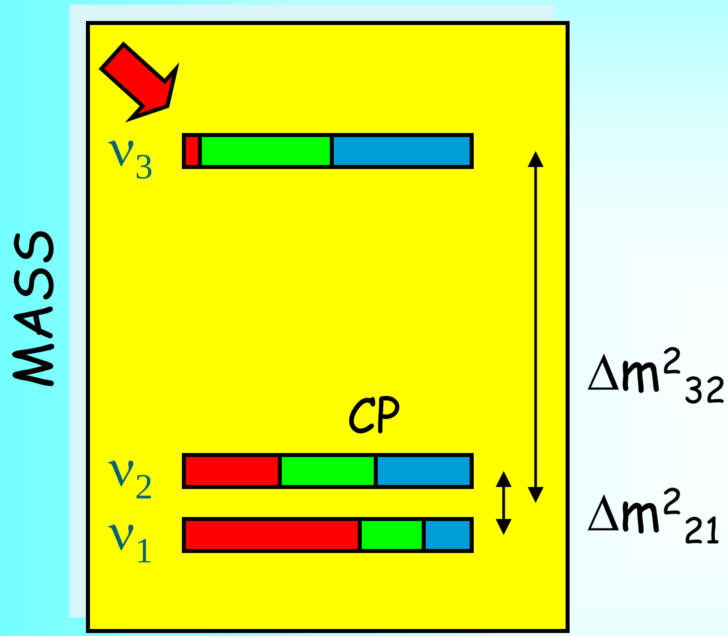
MAX-PLANCK-GESELLSCHAFT

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

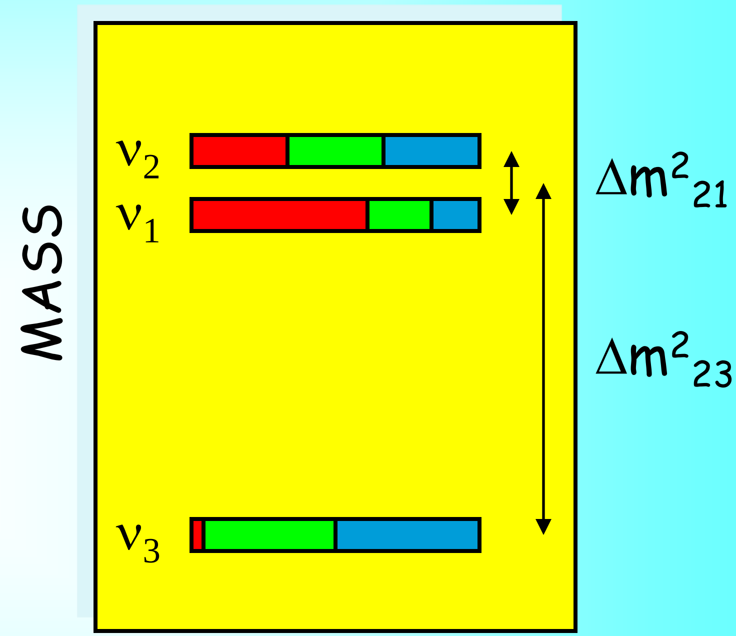
Lepton Mixing



1-3 mixing
2%



Normal mass hierarchy



Inverted mass hierarchy

$\Delta m^2_{32} = 2.5 \times 10^{-3}\ eV^2$

$\Delta m^2_{21} = 7.5 \times 10^{-5}\ eV^2$

CP affects $\mu-$, $\tau-$ flavor distribution in ν_1 ν_2

$\sin^2\theta_{12} \sim 1/3$

$\sin^2\theta_{23} \sim 1/2$

$\sin^2\theta_{13} \sim 0$

TBM, Symmetry?

$V_{CKM} \sim I$

Exlanation?
NEW PHYSICS

Scales of new physics

28 orders of magnitude

GUT - Planck mass

$\frac{V_{EW}^2}{m_\nu}$

High scale seesaw
Quark- lepton symmetry /analogy
GUT

Unification

Electroweak - LHC

Looking under the lamp

Low scale seesaw, radiative mechanisms, RPV, high dimensional operators

mν

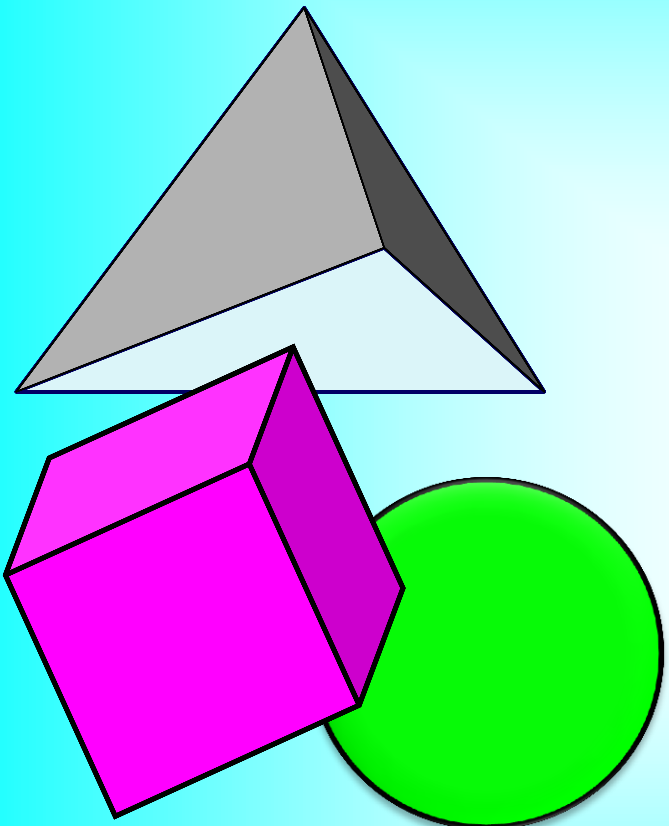
Spurious scale?

eV- sub-eV

Neutrino mass itself is the fundamental scale of new physics

Scale of neutrino masses themselves
Relation to dark energy, MAVAN?

Mixing:



From symmetry
to anarchy
and randomness

Conclisions

No convincing understanding

of mass and mixing pattern although some constructions may have connection to reality.

The problem is to identify correct ones among hundreds ideas, approaches, models

with scepticism: no explanation of quark masses and mixing

Back to bottom

Back to data, search for hints, indications.
Look for connection to other sectors, e.g.
Dark sector of the Universe

May be

Solutions of problems of
visible sector in the Hidden sector

Outline

with *Patric Ludl*
Xiaoyong Chu,
Daniel Hernandez

1. U_pmns vs. Vckm

New arguments to old ideas

2. Scale and hierarchies

Framework

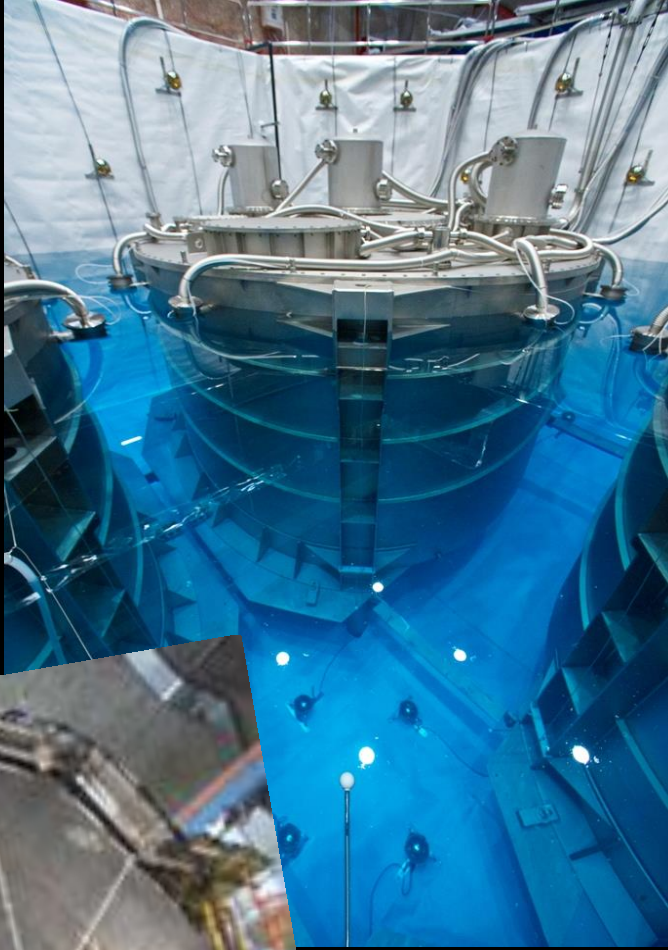
3. Hidden sector and neutrino portal

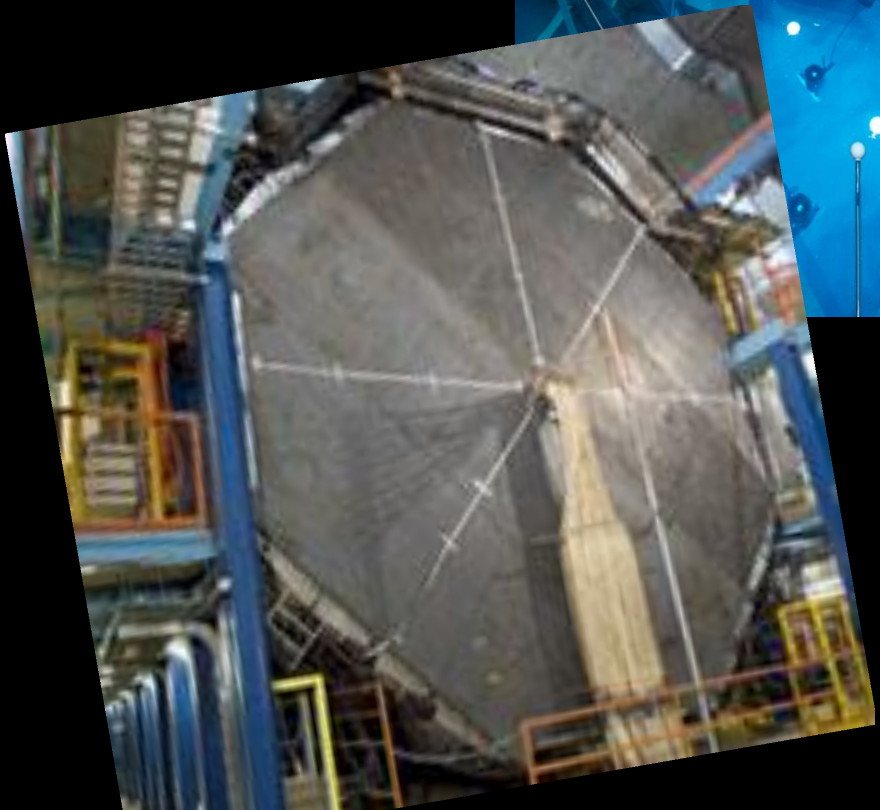
4. Schemes and symmetries

Properties of the framework

5.How to test it?

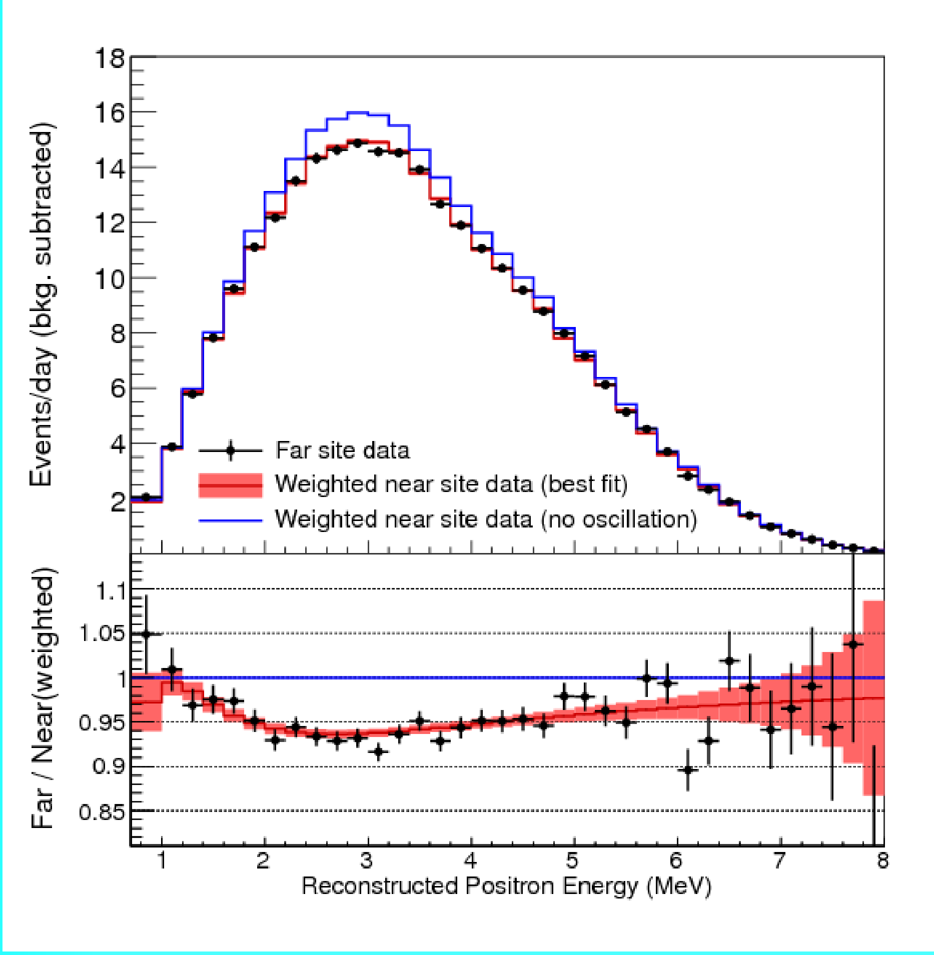
U_pmns versus V_ckm

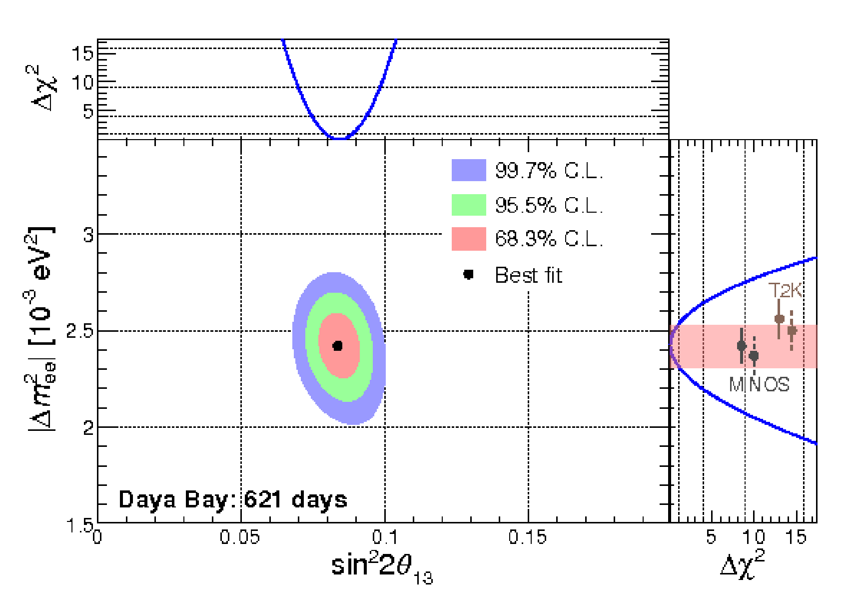


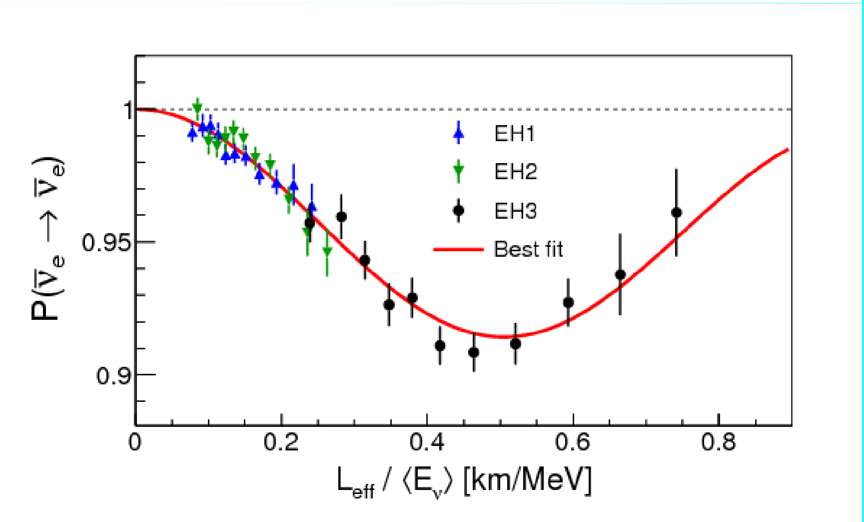


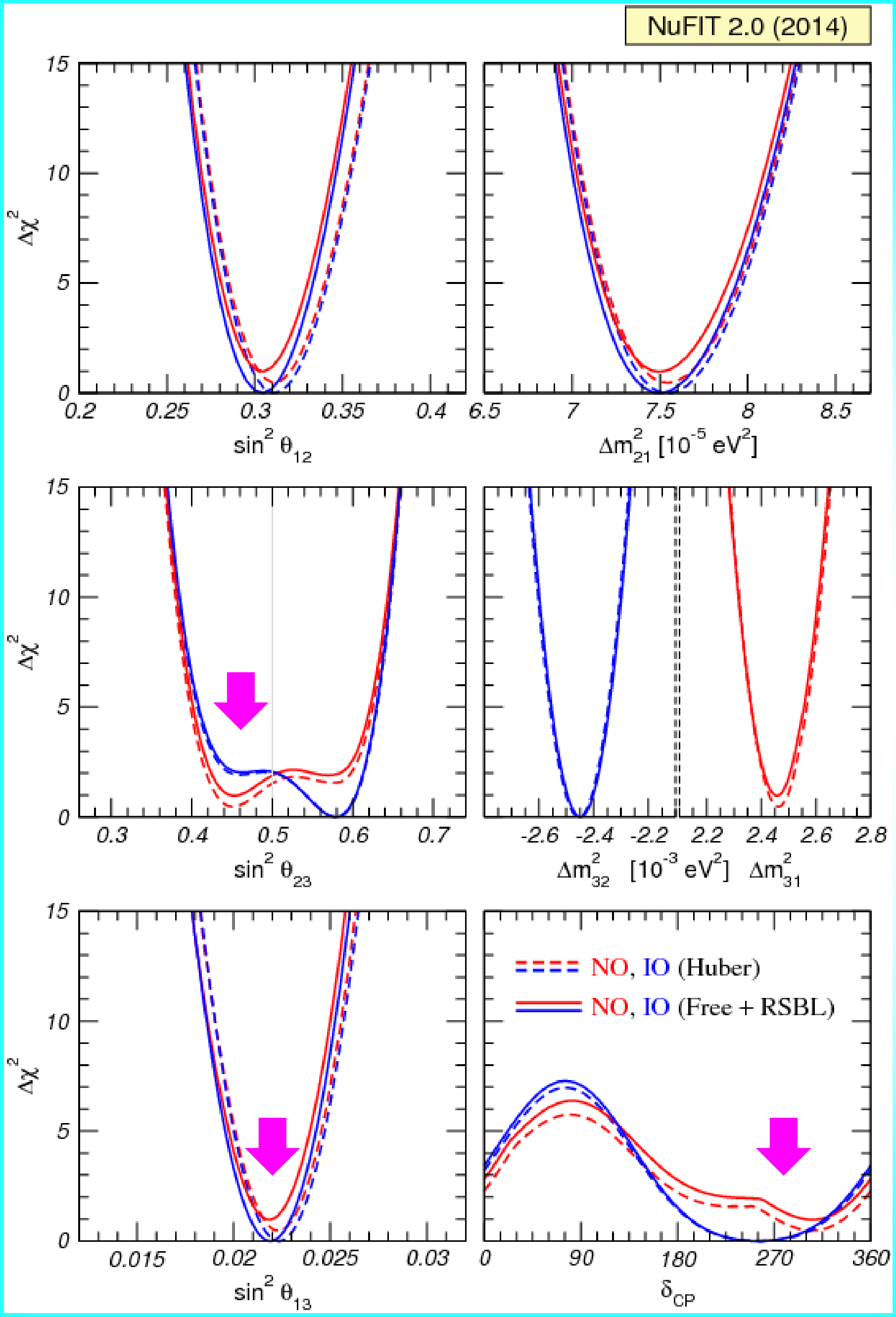
Daya Bay result

Daya Bay Collaboration
(An, F.P. et al.)
arXiv:1505.03456 [hep-ex]









Global 3ν – fit

M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz, **JHEP 1411 (2014) 052,1409.5439 [hep-ph]**

2-3 mixing:

asymmetric for NO and IO
NO: $\sin^2\theta_{23}$ = 0.45, IO: 0.58

Small preference IO and
2nd quadrant

Data confirm prediction

$$\theta_{13} \sim \sqrt{\tfrac{1}{2}}\,\theta_c$$

$$\sin^2\theta_{13} \sim \tfrac{1}{2}\sin^2\theta_C$$

- Phenomenological level — *C. Giunti, M. Tanimoto*
- From QLC (Quark-Lepton Complementarity) — *H. Minakata, A Y S*
- From TBM-Cabibbo scheme — *S. F. King et al*

Now accuracy of measurements permits detailed comparison

Framework

C. Giunti, M. Tanimoto
H. Minakata, A Y S
Z - Z. Xing
J Harada
S Antusch , S. F. King
Y Farzan, A Y S
M Picariello ,etc.

$$U_{PMNS} = U_{CKM}^{+} U_X$$

where $U_{CKM} \sim V_{CKM}$

has similar hierarchical structure determined (as in Wolfenstein parametrization) by powers of

$\lambda = \sin \theta_C$

U_X should be fixed to reproduce correct lepton mixing angles

$U_{CKM} \sim I$ → $U_X \sim U_{TBM}$

can be always written

Deeper sense: reflects/indicates certain theoretical framework

PMNS & CKM

$$U_{PMNS} = U_{CKM}^{+}\, U_{X}$$

From the Dirac matrices of charged leptons and neutrinos

Related to (any) mechanism that explains smallness of neutrino mass

New neutrino structure

Neutrino portal

Two types of new physics and partial relations

CKM type new physics

Neutrino new physics

Framework and prediction

C. Giunti, M. Tanimoto
H. Minakata, A Y S
Z - Z. Xing
J Harada
S Antusch , S. F. King
Y Farzan, A Y S
M Picariello ,etc.

$$U_{PMNS} = U_{CKM}^{+} U_X$$

where $U_{CKM} \sim V_{CKM}$
has similar hierarchical structure determined (as in Wolfenstein parametrization) by powers of

$\lambda = \sin\theta_C$

$U_X = U_{23}(\pi/4)\, U_{12}$

needed to explain 2-3 mixing

arbitrary; no 1-3 rotation (or very small)

$U_{PMNS} = U_{CKM}^{+} U_{23}(\pi/4)\, U_{12}$

$U_X \sim U_{TBM}$

In the first approximation $\sim U_{12}(\theta_c)^{+} U_{23}(\pi/4)\, U_{12}$

permutation - to reduce the lepton mixing matrix to the standard form

$$\sin\theta_{13} \sim \frac{1}{\sqrt{2}} \sin\theta_C$$

CKM corrections

take whole V_{CKM} with small elements V_{td}, V_{cb}, etc.

→ this will give also corrections to 2-3 mixing

take in general, non-maximal rotation $U_{23}(\theta^x_{23})$:

$U_X = \Gamma(\alpha)\, U_{23}(\theta^x_{23})\, U_{12}(\theta^x_{12})$ $\quad \Gamma(\alpha) = \mathrm{diag}(1, 1, e^{i\alpha})$ phase matrix

$$\sin^2\theta_{13} = \sin^2\theta^x_{23}\,\sin^2\theta_C\left[1 - 2\cot\theta^x_{23}\cos(\alpha - \phi_{td})\,|V_{td}|/|V_{cd}|\right]$$

where $\phi_{td} = \mathrm{Arg}\, V_{td}$

In Wolfenstein parametrization

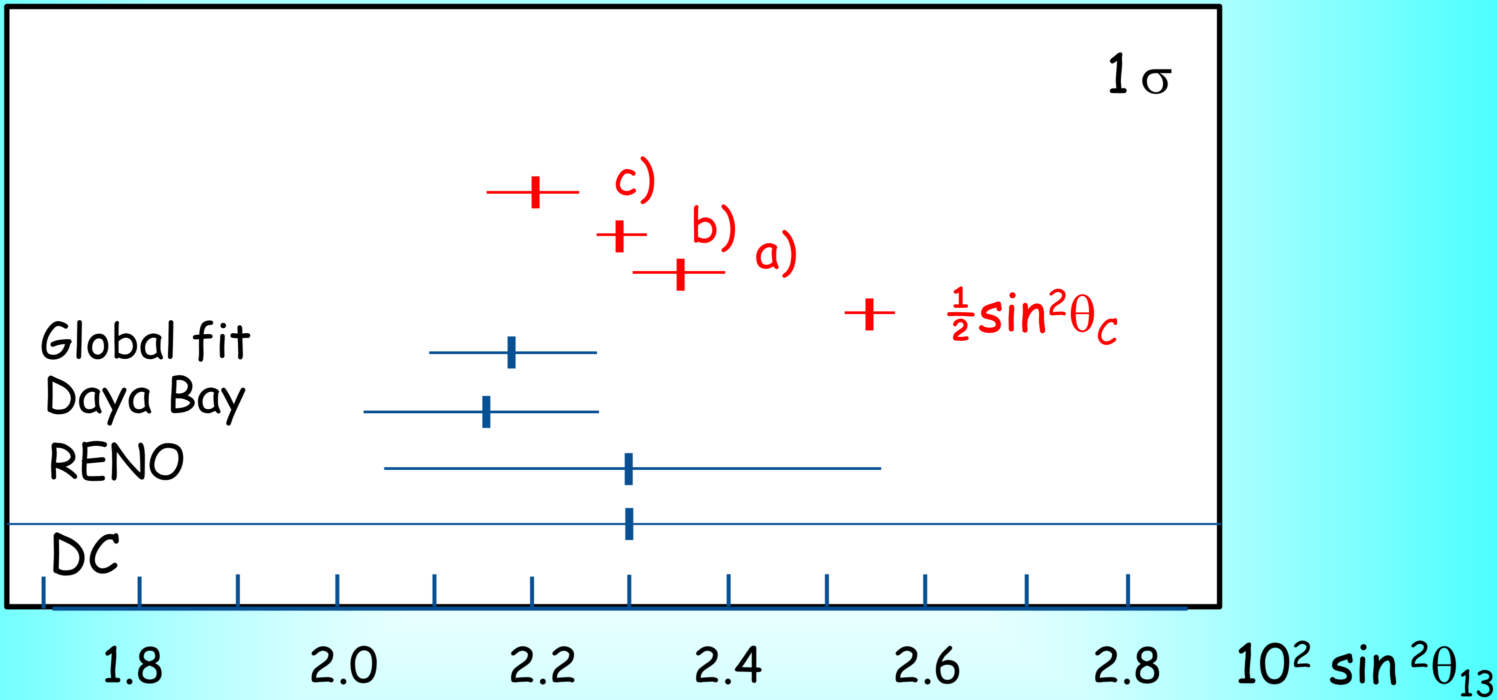
$$\sin^2\theta_{13} = \sin^2\theta^x_{23}\,\lambda^2\left[1 - 2A\lambda^2[(1-\rho)^2 + \eta^2]^{1/2}\cot\theta^x_{23}\cos(\alpha - \phi_{td})\right]$$

$$\tan^2\theta_{23} = \tan^2\theta^x_{23}\,(1 - \lambda^2)\left[1 - 2A\lambda^2[(1-\rho)^2 + \eta^2]^{1/2}\sin^{-1}2\theta^x_{23}\cos\alpha\right]$$

$\tan^2\theta_{23} = \tan^2\theta^x_{23}\,\kappa(\alpha)$ $\quad \kappa = (1 - \lambda^2)\left[1 - 4A\lambda^2[(1-\rho)^2 + \eta^2]^{1/2}\cos\alpha\right]$

Excluding θ^x_{23} $\quad \sin^2\theta_{13} = f(\theta_{23}, \alpha)$

Confronting with data



a) CKM –corrections; $\sin^2\theta^x{}_{23}$ = 0.50

b) No CKM corrections, $\sin^2\theta^x{}_{23}$ = 0.45 ($\sin^2\theta_{23}$ = 0.40)

c) CKM-corrections, $\sin^2\theta^x{}_{23}$ = 0.47 ($\sin^2\theta_{23}$ = 0.42)

$\cos(\alpha - \phi_{td}) = 1$

What does this mean?

H. Minakata, A Y S

………………………………………

Quarks and leptons know about each other,
Q L unification, GUT

Common flavor symmetries

Some additional physics is involved in the lepton sector which explains smallness of neutrino mass and difference of the quark and lepton mixing patterns

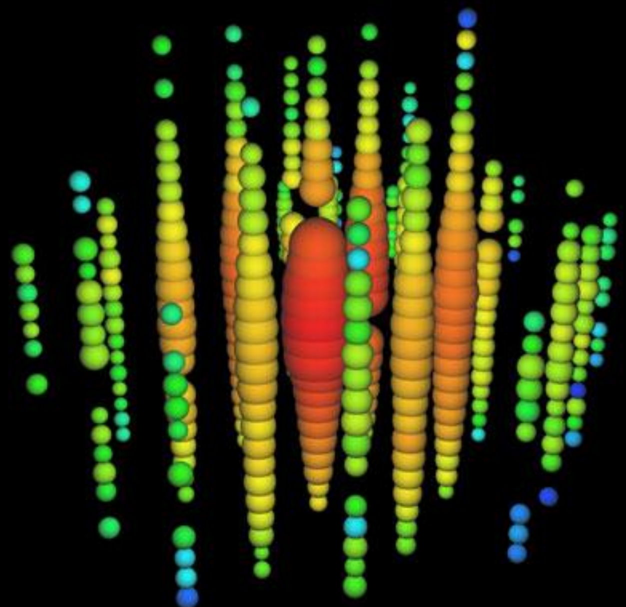
Indicates SO(10)

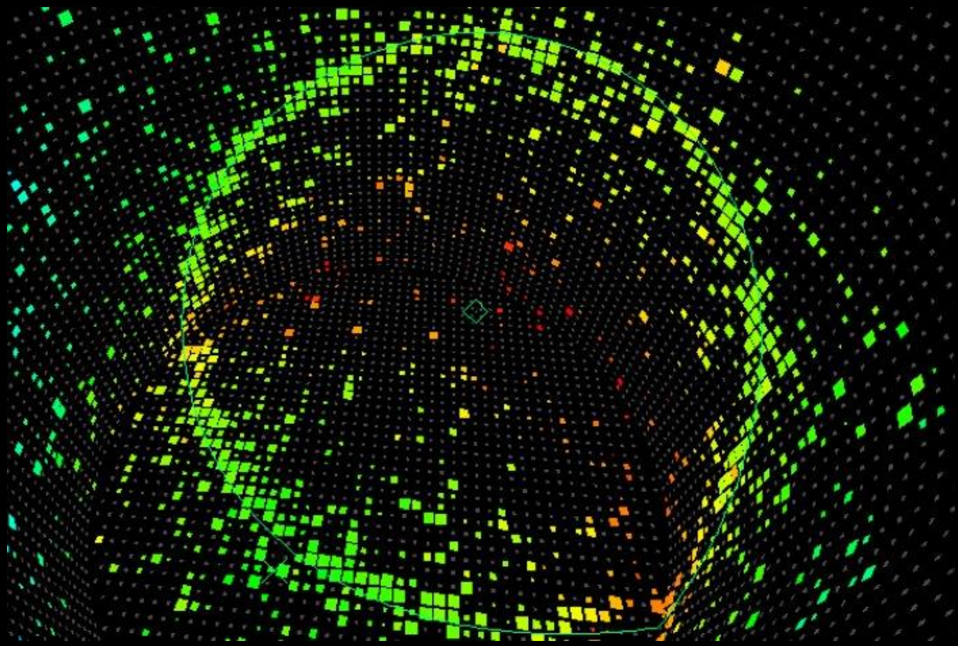
Two types of new physics

CKM

Neutrino

Scales and Hierarchies

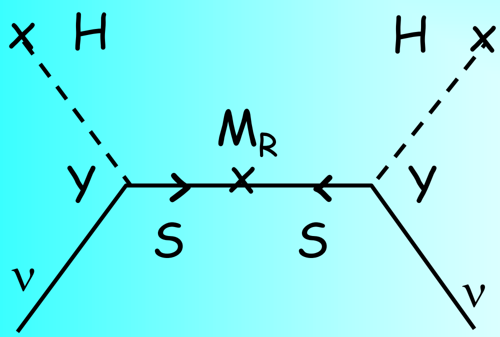




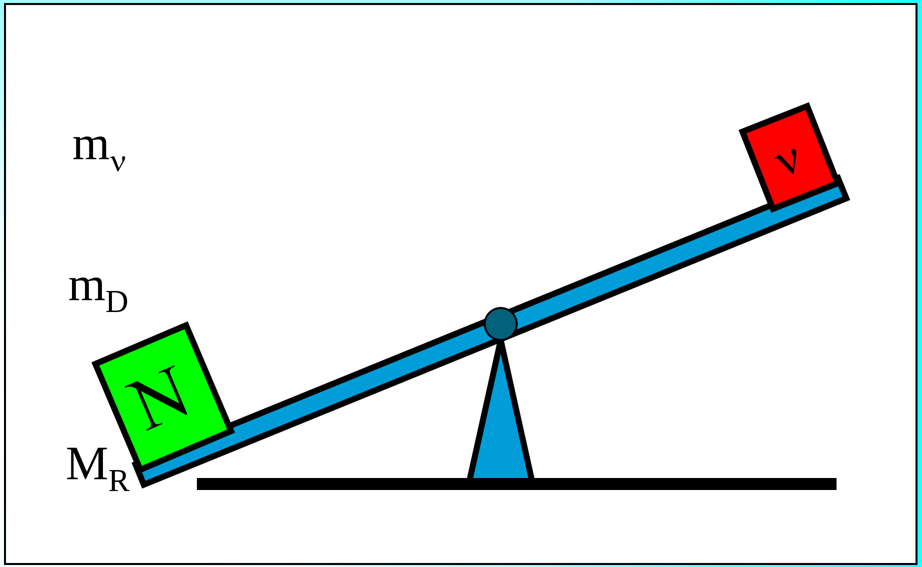
Framework can be realized in

See-saw

P. Minkowski
T. Yanagida
M. Gell-Mann, P. Ramond, R. Slansky
S. L. Glashow
R.N. Mohapatra, G. Senjanovic



$m_D = y\langle H\rangle$



Mass matrix:

$$\begin{array}{c|cc} & \nu & N \\ \hline \nu & 0 & m_D \\ N & m_D^T & M_R \end{array}$$

if $M_R \gg m_D$ ➡

$$m_\nu = - m_D^T \frac{1}{M_R} m_D$$

IMPORTANT:

M_R can be related to GUT / Planck scale

Framework and Seesaw mechanism

Natural and simplest realization of the framework is the seesaw type I

$$m_\nu = - m_D (M_R)^{-1} m_D^T$$

$$m_D = U_L (m_D^{diag}) U_R^+$$

B Dasgupta A.S

In the simplest SO(10): $U_L = V_{CKM}^*$

then U_x is the matrix which diagonalizes

$$M_X = - m_D^{diag} U_R^+ (M_R)^{-1} U_R^* m_D^{diag}$$

that is

$$M_X = U_X M_X^{diag} U_X^T = U_X m_\nu^{diag} U_X^T \sim m_{TBM}$$

$$M_R = - m_D^{diag} (m_{TBM})^{-1} m_D^{diag}$$

very hierarchical, Generated by seesaw itself?

→ Double seesaw

Scale of seesaw

$$M_R = - m_D^T \frac{1}{m_\nu} m_D$$

q – l similarity: $m_D \sim m_q \sim m_l$

for one third generations $M_R \sim 2\ 10^{14}$ GeV

$M_R \sim$
- $M_{GUT} \sim 10^{16}$ GeV — for the heaviest in the presence of mixing
- 10^{8} - 10^{14} GeV — $\frac{M_{GUT}^2}{M_{Pl}}$ double seesaw
- 10^{16} - 10^{17} GeV — many heavy singlets (RH neutrinos) …string theory $N \sim 10^2$

also in favor of high scale:

Gauge coupling unification

Leptogenesis

Double Seesaw

R.N. Mohapatra
J. Valle

Three additional singlets S which couple with RH neutrinos

$$\begin{pmatrix} 0 & m_D^T & 0 \\ m_D & 0 & M_D^T \\ 0 & M_D & M_S \end{pmatrix} \begin{pmatrix} \nu \\ \nu^c \\ S \end{pmatrix}$$

M_S - scale of B-L violation

$M_S \sim M_{Pl}$, $M_D \sim M_{GU}$

$M_S >> M_D$

$\Rightarrow$ $m_\nu = m_D^T M_D^{-1T} M_S M_D^{-1} m_D$

$M_R = M_D^T M_S^{-1} M_D$ can be very hierarchical

$m_D = A M_D$ $\Rightarrow$ $m_\nu \sim M_S$

Hierarchical Dirac structures disappear

Can realize scenario with two types of new physics involved

Screening of Dirac structures

A.Y.S
M. Lindner,
M.A. Schmidt
A.Y.S

$d = M_D^{-1} m_D$ → $m_\nu = d^T M_S d$

screening factor

1. Complete screening of the Dirac structure

$m_D = A M_D$ as a consequence of symmetry $A = v_{EW}/V_{GUT}$

$d = A I$ → $m_\nu = A^2 M_S$

Light neutrino mass matrix is determined by the heaviest one M_S

2. Partial screening of the Dirac structure

m_D, M_D = diag → d = diagonal e.g. d = diag (a, 1, 1)

$d = U_{23}^{max}$ or U_ω

Affect mixing

S belong to Hidden sector

Hidden sector and neutrino portal

LH

Hidden sector

singlet of the SM
symmetry group,
also invisible

Populated
by new

fermions – sterile neutrinos, etc
scalar bosons – axions, majorons, flavons
Gauge bosons - dark photons, etc,

Fill in

The Dark universe

DM
DE
BAU

Responsible for

Anomalies

LSND/MiniBooNE
Reactor
Gallum
3.5 keV line?

explains

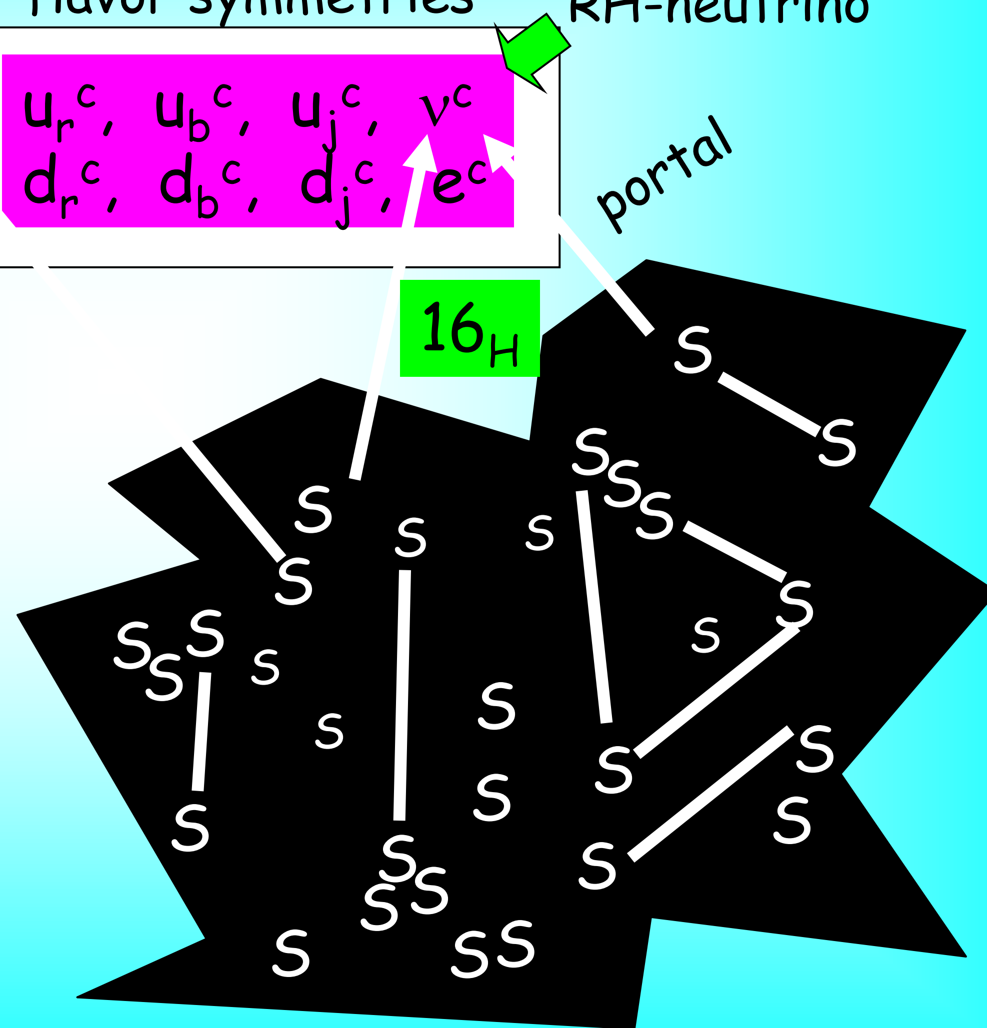
Neutrino masses and mixing

It looks like,
The Problems are in the Visible sector
Solutions - in the Hidden one

Set-up

SO(10) GUT + hidden sector + flavor symmetries

16 : $u_r\,,\ u_b\,,\ u_j\,,\ \nu$; $d_r\,,\ d_b\,,\ d_j\,,\ e$ | $u_r^c,\ u_b^c,\ u_j^c,\ \nu^c$; $d_r^c,\ d_b^c,\ d_j^c,\ e^c$

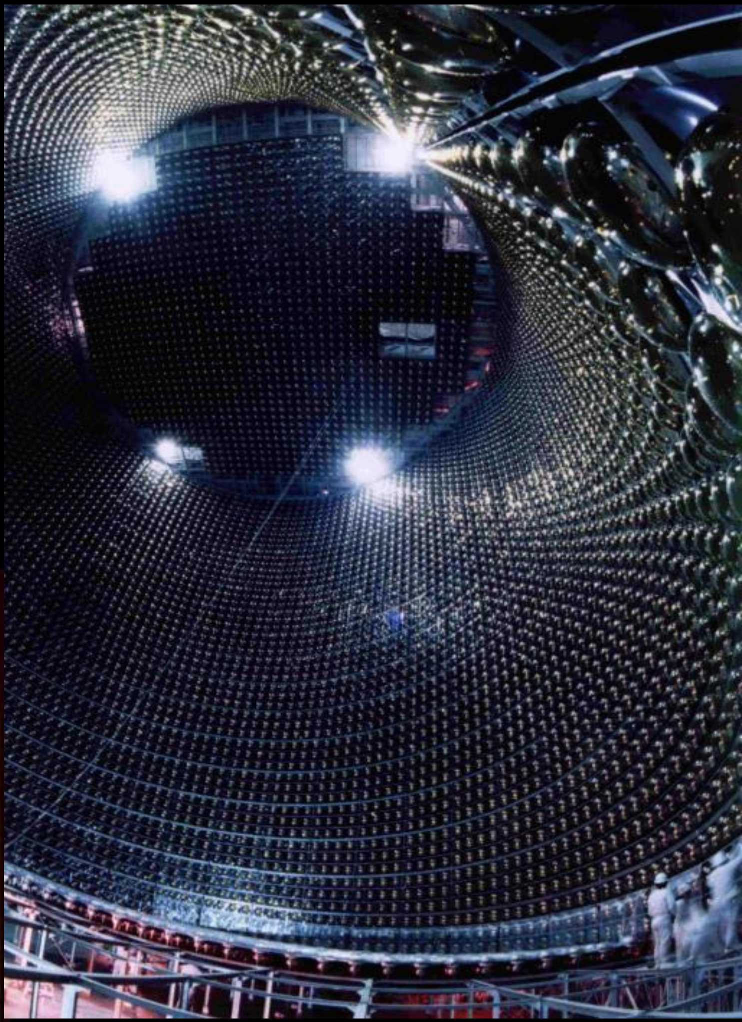


Double seesaw → smallness of neutrino mass

Can realize framework
$U_{PMNS} = U_{CKM}^{+}\, U_X$

Flavor symmetries at very high scales, above GUT
Symmetries in S-sector

Schemes and Symmetries



SO(10) and double seesaw

Patrick Ludl A.S

F-F	$Y_{ij}\ 16_F^i\ 16_F^j\ 10_H$	m_D	$m_D^l = m_D$
F-S	$Y_{ij}''16_F^i\ 1_S^j\ 16_H$	M_D	
S-S	$h_{ijk}\ 1_S^i\ 1_S^j\ 1_H^k$	M_S	

In general $Y \sim y\ (\langle\phi\rangle / \Lambda)^n$

For third generation we take n = 0 i.e. the mass is generated at the renormalizable level

No mixing is generated by F-F at this level

Allow to separate CKM and Neutrino new physics

Basis fixing symmetry

Although mixing is not generated, masses are generated by the F-F term

Information about states with definite masses
should be communicated to the Hidden sector

This can be done by symmetry which
- distinguishes three 16-plets, and
- makes the F-F interactions diagonal

G_{basis}

basis fixing
Group (portal)

The smallest group is $G_{basis} = Z_2 \times Z_2$

with charge assignment (1, 0), (0,1), (0,0) ← powers of $e^{i\pi}$

(other assignments lead to the same results)

Matrix of charges of F-F couplings

(0, 0), (1,1), (1,0)
(1, 1), (0,0), (0,1)
(1, 0), (0.1), (0.0)

Both distinguishes states and makes couplings diagonal

assignment

(1, 0), (0,1), (1,1) with nontrivial charges fixes 3 generations

Scenarios and realizations

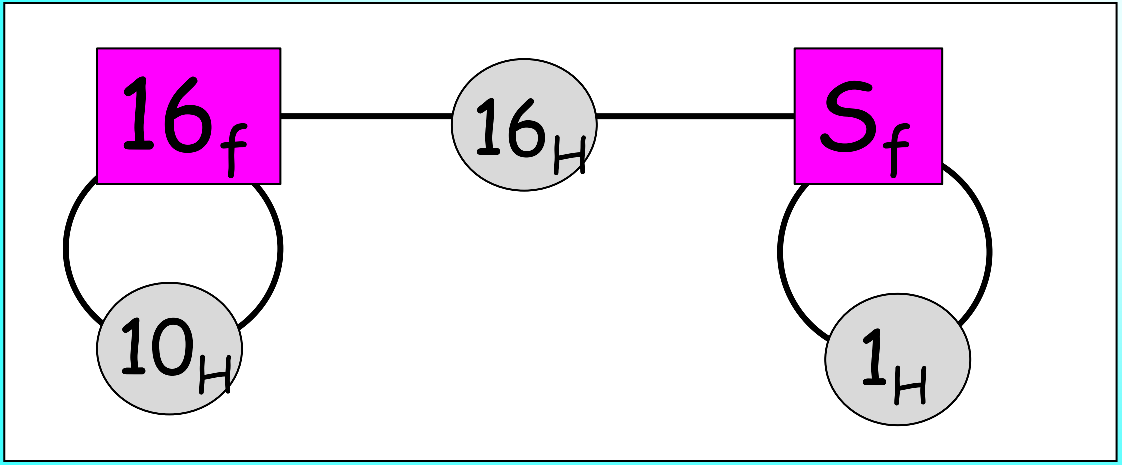
Patrick Ludl A.S

F-F and F-S couplings are diagonal in the same basis

$m_D \sim M_D = diag$

So, essentially we construct M_X

Mixing is produced by S-S coupling i.e. in M_S



Realization

S as mediators which propagate info from visible to hidden sectors

$G_{basis} = Z_2 \times Z_2$ $G_{aux} = Z_3$ $\omega = e^{i2\pi/3}$ to avoid NR couplings of 1_H with 16_F

	16_F	1_S	1_H	10_H	16_H
$Z_2 \times Z_2$	(1, 0) (0,1) (0,0)	(1, 0) (0,1) (0,0)	(0,1) (0,0)	(0,0)	(0,0)
Z_3	ω	ω	ω	ω	ω

the same charges

$$Y_i\, 16_F^i\, 16_F^i\, 10_H + Y_i' 16_F^i\, 1_S^i\, 16_H + h_{ijk}\, 1_S^i\, 1_S^j\, 1_H^k$$

diagonal

$m_D = \langle 10_H \rangle$ diag (Y_1, Y_2, Y_3) $M_D = \langle 16_H \rangle$ diag (Y'_1, Y'_2, Y'_3)

for third generation renormalizable coupling with , $Y_3 = 1$, $Y'_3 = 1$

Hierarchy of masses due to $Y_1 \ll Y_2 \ll Y_3$, $Y'_1 \ll Y'_2 \ll Y'_3$

Due to identical flavor charges of interaction one may expect that $Y_i \sim Y'_i$

This might be residual of some further unification 16 and 1

CKM-physics

Mixing

Screening matrix: $d = M_D^{-1}\, m_D = (\langle 10_H \rangle / \langle 16_H \rangle)\ \mathrm{diag}(Y_1/Y'_1,\ Y_2/Y'_2,\ Y_3/Y'_3)$

Mixing originates from S-S interactions provided that the scalars 1_H have non-trivial $Z_2 \times Z_2$ charges

$Z_2 \times Z_2$ charges of F-F, F-S and S-S terms

(0, 0), (1,1), (1,0)
(1, 1), (0,0), (0,1)
(1, 0), (0.1), (0.0)

Due to $G_{aux} = Z_3$

- 1_H do not couple with FxF and FxS
  → only diagonal terms are allowed
- bare mass terms in SxS are forbidden

With charge assignment (0,1), (0,0) for 1_H

$$M_S = \begin{pmatrix} x & 0 & 0 \\ 0 & x & x \\ 0 & x & x \end{pmatrix}$$

Elements 1-2 and 1-3 can be produced with additional (1,0), (1,1) flavons or due to interactions with other hidden fermions

Mixing

Putting things together

$M_X = d^T M_S d$

should be of m_{TBM} form

For all parameters of the same order produces large mixings
Enough parameters, further model building is needed

Interesting possibilities:

M_S has slightly smaller 1-2 and 2-3 elements
d =diag(a, 1, 1) a < 1 can produce TBM mass matrix

d = AI $M_X = M_S$

There is an accidental (?) 2-3 permutation symmetry

Realization

16_H as mediators

$G_{basis} = Z_2 \times Z_2 \times Z_4$

	16_F	$16_H{}^i$	10_H	1_S	1_H
$Z_2 \times Z_2$	(1, 0) (0,1) (0,0)	(1, 0) (0,1) (0,0)	1	1	1
Z_4	1	(i, 1, -1)	1	(-i, 1, -1)	(-1, i, -i)
Z_3	ω	ω	ω	ω	ω

1_S are singlet of $Z_2 \times Z_2$

Additional Z_4 to fix basis and communicate info to the hidden sector

Three $16_H{}^i$ charged with respect to both groups play role of mediators

$$Y_i\, 16_F{}^i\, 16_F{}^i\, 10_H + Y_i' 16_F{}^i\, 1_S{}^i\, 16_H{}^i + h_{ijk}\, 1_S{}^i\, 1_S{}^j\, 1_H{}^k$$

$$m_D = \langle 10_H \rangle \,\mathrm{diag}\,(Y_1, Y_2, Y_3)$$

$$M_D = \mathrm{diag}\,(Y'_1 \langle 16_H{}^1 \rangle,\; Y'_2 \langle 16_H{}^2 \rangle,\; Y'_3 \langle 16_H{}^3 \rangle)$$

Mixing

Here more flexibility in construction of M_S

Z_4 charges of 1_S (3, 0, 2) This implies of charges of 16_H^i (1, 0, 2)

The matrix of Z_4 charges of S-S coupling terms

$$\begin{pmatrix} 2 & 3 & 1 \\ \dots & 0 & 2 \\ \dots & \dots & 0 \end{pmatrix}$$

with Z_4 charges of 1_H (2, 1, 3) Produces the mass matrix

$$\begin{pmatrix} a & c & d \\ \dots & 0 & b \\ \dots & \dots & 0 \end{pmatrix}$$

Correspond to quasi-degenerate Spectrum (a = b)

For c ~ d it has approximate 2-3 permutation symmetry which gives maximal 2-3 mixing and zero 1-3 mixing

Mixing

Another possibility

$G_{basis} = Z_2 \times Z_2 \times Z_7$

Z_7 charges of 1_S (0, 2, 3) (this implies of charges of 16_H^i (0, 5, 4)

The matrix of Z_4 charges of S-S coupling terms

$$\begin{pmatrix} 0 & 2 & 3 \\ \ldots & 4 & 5 \\ \ldots & \ldots & 6 \end{pmatrix}$$

Z_7 charges of 1_H (1, 2, 3)

Produces the mass matrix

$$M_{SS} = \begin{pmatrix} 0 & 0 & 0 \\ \ldots & a & b \\ \ldots & \ldots & c \end{pmatrix}$$

with dominant 2-3 block →
hierarchical mass spectrum
maximal 2-3 mixing and zero 1-3 mixing

Small elements can be generated by additional flavons
or higher dimension operators with product of 2 flavons

Variations

Three 16_H^i can be substituted

$$16_H^i \rightarrow 16_H \; (1_\eta^i/\Lambda)$$

16_H and 1_η^i transform as (- 1, -1) with respect to new connecting group Z_2

All other fields are singlets of this group

$$\langle 1_\eta^i \rangle \sim M_{GUT}$$

$$\langle 16_H \rangle \sim \Lambda \sim M_{Pl}$$

To avoid large effects of higher dimension operators

SO(10) is broken near M_{Pl}

CKM physics

includes
- hierarchy of Yuakawas Y_i , Y'_i
- CKM mixing
- difference of masses of upper and down quarks
- difference of masses of down quarks and charged leptons

Related to breaking of S(10)

Framework allows to disentangle the CKM physics and neutrino physics

Hierarchy of masses

due to hierarchy of couplings: $Y_1 \ll Y_2 \ll Y_3$, $Y'_1 \ll Y'_2 \ll Y'_3$

→ in turn, due to operators of different order:

3rd generation renormalizable coupling with , $Y_3 = 1$, $Y'_3 = 1$

2nd generation: $Y \sim y\,(\langle\phi\rangle / \Lambda)$

1st generation: $Y \sim y\,(\langle\phi\rangle / \Lambda)^2$

Realization

$G_{Yukawa} = Z_5$

Scheme with 16_H^i mediator

new flavon

	16_F^i	16_H^i	1_Y
Z_5	(1, 3, 0)	(1, 3, 0)	4

all other fields are singlets

powers of $e^{i2\pi/5}$

$Y_1 = y_1 (\langle 1_Y \rangle/\Lambda)^2$

$Y_2 = y_2 (\langle 1_Y \rangle/\Lambda)$

$Y_3 = y_3$

produces geometric hierarchy of masses of the upper component

Scheme with 1_S^i mediator

without non-renormalizable terms

$Z_2 \times Z_2$

	16_F	1_F^i	1_Y	1_H (0, 1)	1_H (0, 0)	1_H (0, 0)
Z_5	(1, 3, 0)	(1, 3, 0)	4	2	4	0

allows to get dominant 2-3 block in M_S
but now CKM and Nu physics are entangled

CKM Mixing

Associated to breaking of $Z_2 \times Z_2$

One or more additional 10_H

Different 10_H give masses for upper and down fermion components (ensures different mass hierarchies)

		Z_2
10_H^u	with $v_d = 0$	+
10_H^d	with $v_u = 0$	-

CKM mixing originates from the down sector: 10_H^d interactions

additional $G'_{aux} = Z'_2$ can be introduced to distinguish them

additional higgs singlets 1_ξ^i with $Z'_2 = -1$

$10_H^d \rightarrow 10_H^d\,(1_\xi^i/\Lambda)$

With of $Z_2 \times Z_2$ charge assignment (0,0), (0,1), (0, 1) for 1_ξ^i :

Alternatively - several 10_H^d with $Z_2 \times Z_2$ charges

$Z_2 \times Z_2$ charges of F-F

(0, 0)	(1,1)	(1,0)
(1, 1)	(0,0)	(0,1)
(1, 0)	(0.1)	(0.0)

Non-abelian discrete symmetries

Approximate non-abelian symmetries from interactions with many singlets and decoupling of heavy degrees of freedom

S_2 - S_3 permutation symmetry gives equality of 12- and 13- elements as well as 22- and 33- elements of the matrix M_{SS}

This permutation $G_{perm} = Z_2$ is not consistent with basis symmetry $Z_2 \times Z_2$ since S_2 and S_3 have different $Z_2 \times Z_2$ charges.

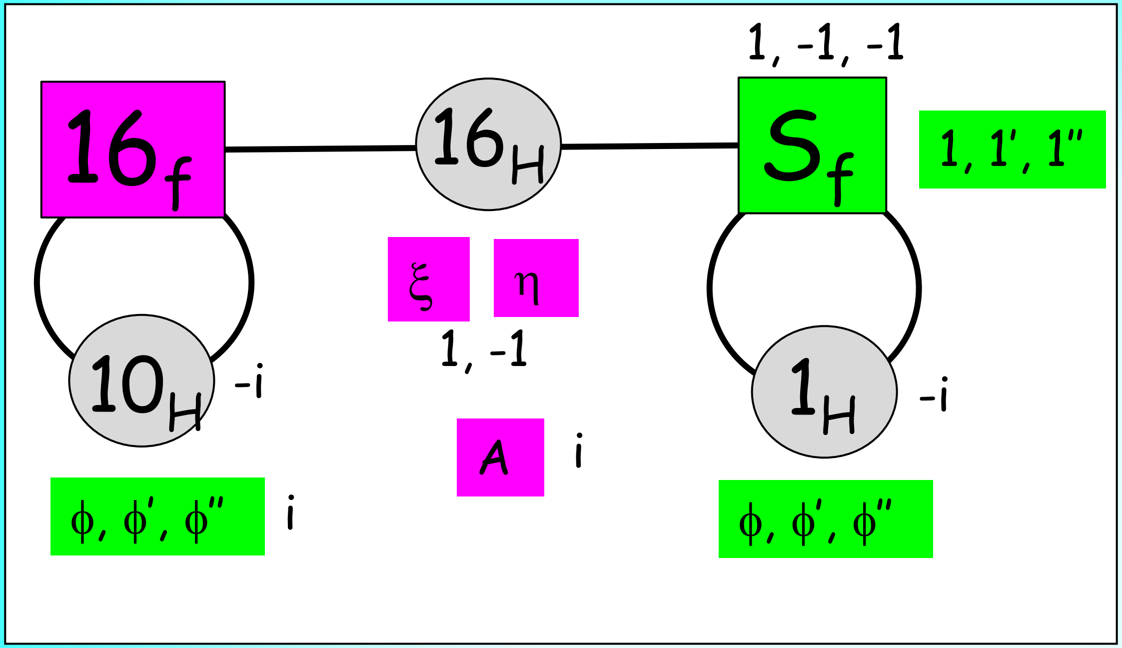
The violation is explicit in F-S interactions

However , these interactions are at GUT energies, and therefore their effect on M_{SS} is very small

One can consider semi-direct product of G_{perm} and $G_{basis} = Z_2$ and embed them in a single non-abelian group.
This group can be spontaneously broken in the F-S sector, which however requires substantial complication of the model.

A scheme for TBM

Xiaoyong Chu, A.S



Rep. 3 of A_4

1, 1', 1''

Z_4

Auxiliary field A

$m_D^l = m_D$
diagonal

$\frac{1}{M_D}$

M_S
2-3 maximal mixing

→ Tri-bimaximal mixing

$M_D = V_{diag} U_\omega$

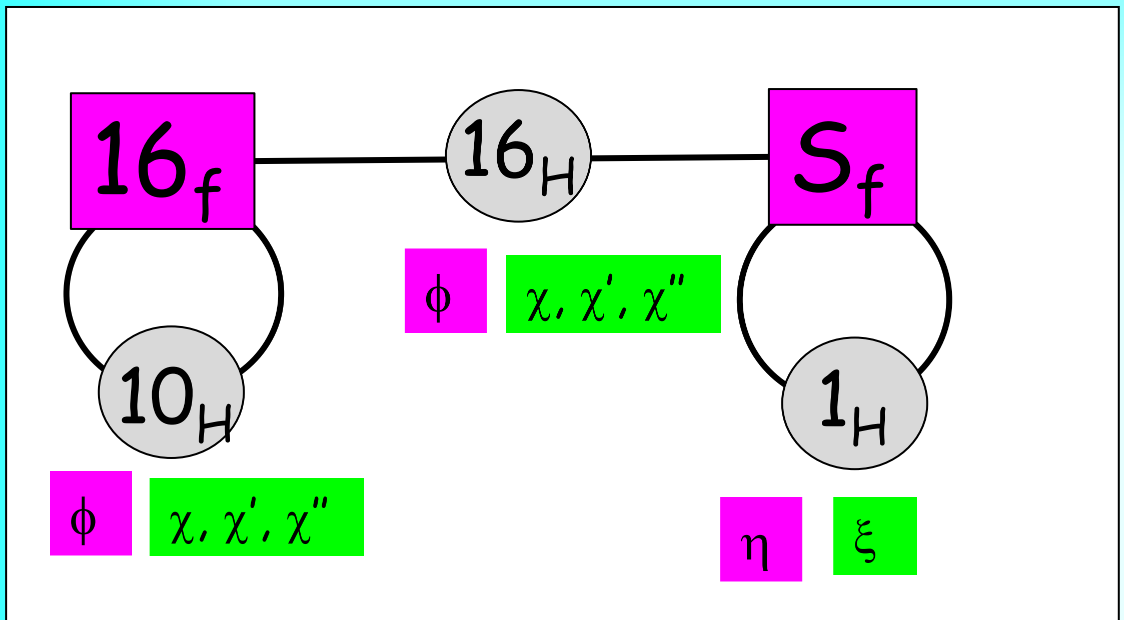
magic matrix

A scheme for BM

Xiaoyong Chu, A.S

Rep. 3

1, 1', 1''



$m_D^l = m_D$ maximal 1-2 mixing

$\frac{1}{M_D}$

M_S

→ Bi-maximal mixing

$m_D \sim M_D$ screening

No hope to test?

How to test?

Hopeless?

Nothing should be observed at LHC which is responsible for neutrino masses

If something is observed against (excludes) framework

Special value of CP-phases

Light sterile neutrinos

Dark mater

Inflation

Leptogenesis

CP-phase and the framework

$U_{PMNS} \sim V_{CKM}^{+} U_X$

If the only source of CP violation

No CPV

B. Dasgupta, A.S.

$\sin\theta_{13} \sin\delta_{CP} = (-\cos\theta_{23}) \sin\theta_{13}^{q} \sin\delta_q$

$\delta_q = 22.5^0$

λ λ^3

$\sin\delta_{CP} \sim \lambda^3/s_{13} \sim \lambda^2 \sim 0.046$

$\delta_{CP} \sim -\delta$ or $\pi + \delta$

where $\delta = (s_{13}^{q}/s_{13})\, c_{23} \sin\delta_q$

Implications

If the phase δ_{CP} deviates substantially from 0 or π, new sources of CPV beyond CKM

New sources may have specific symmetries which lead to particular values of δ_{CP} e.g. $-\pi/2$

In general

neglecting terms of the order ~ λ^3

$$\sin \delta_{CP} = s_{13}^{-1} [\sin(\alpha_\mu + \delta_X) V_{ud} |X_{e3}| - \sin \alpha_e |V_{cd}| X_{\mu 3}]$$

here α_μ , δ_X and α_e are parameters of U_X

Some special values of δ_{CP} can be obtained under certain assumptions

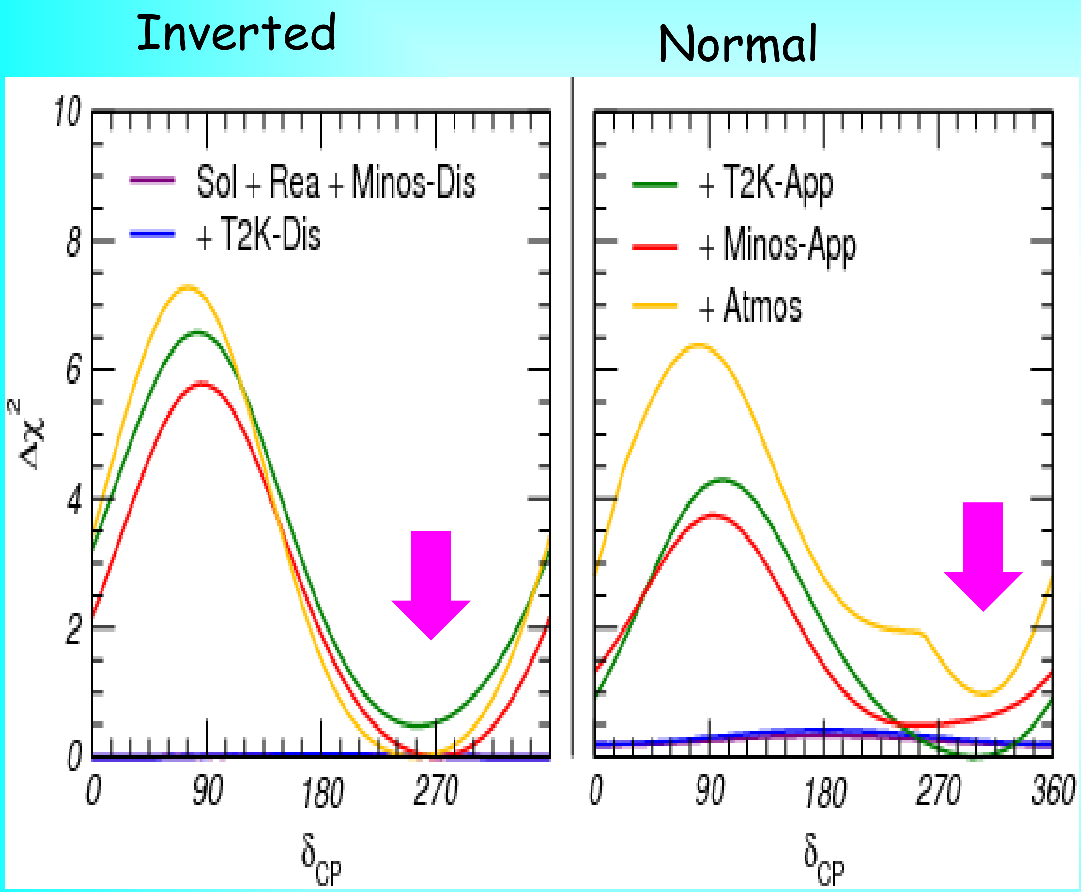
if $X_{e3} = 0$ we have $\sin \delta_{CP} \sim - \sin \alpha_e$

if $\alpha_e = \pi/2$ $\delta_{CP} \sim 3\pi/2$

One can find structure of the RH sector which lead to these conditions

CP-phase

M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz, JHEP 1411 (2014) 052, 1409.5439 [hep-ph]



Contribution of different sets of experimental results to the determination of the mass ordering, the octant of θ_{23} and of the CP violating phase.

Genesis of determination

Solar
Reactors
MINOS dis

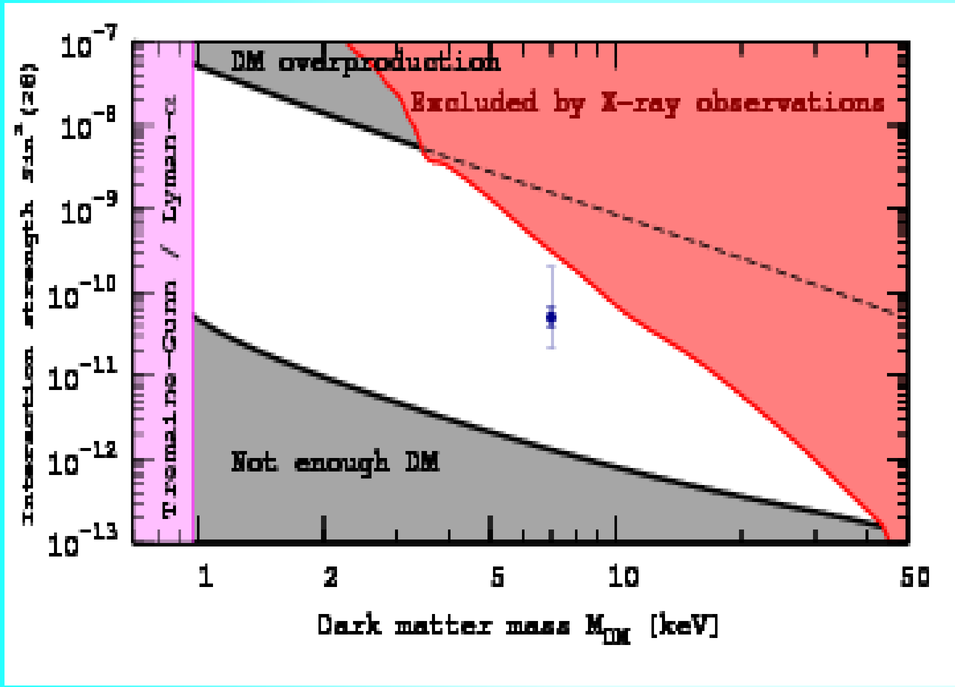
\+ T2K - Dis

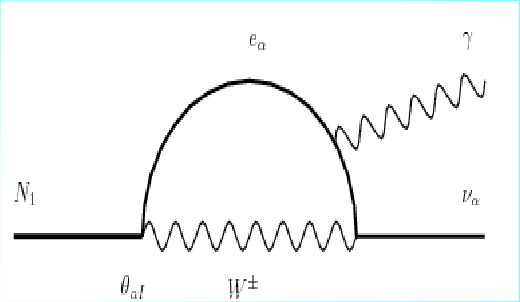
\+ T2K-App

\+ MINOS-App

\+ Atmospheric

WDM from Hidden sector





The blue point: the best-fit value from M31 (Andromeda galaxy). Thick error bars are ±1σ limits on the flux. Thin error bars correspond to the uncertainty in the DM distribution in the center of M31.

A Boyarsky et al, 1402.4119

$\theta_{aS}^2 \sim\ 2\ 10^{-11}$

$\delta m \sim \theta_{aS}^2\ m\ \ \sim (1 - 2)\ 10^{-7}$ eV

- below any relevant scale in the neutrino mass matrix ~ 10^{-3} eV

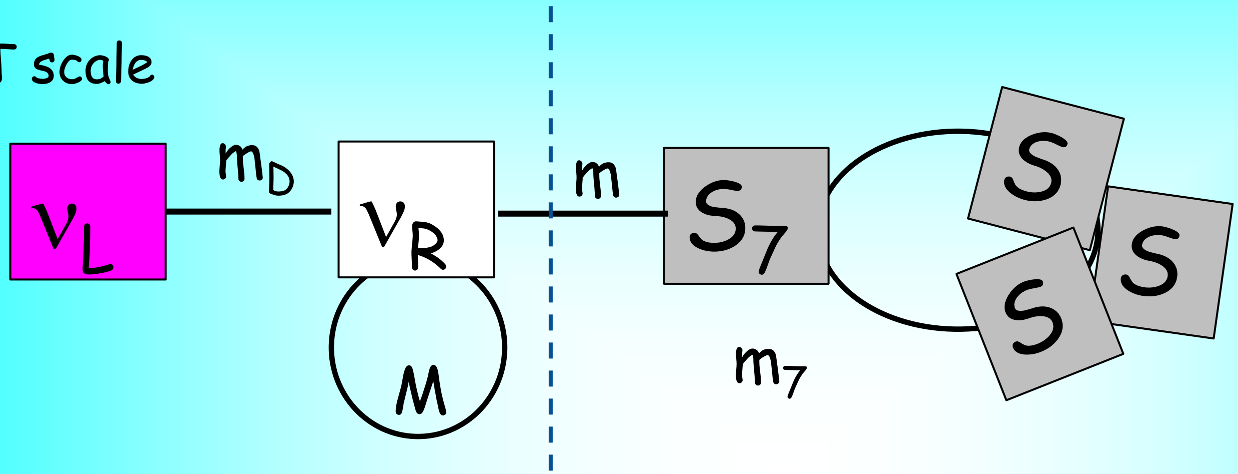
→ does not participate in neutrino mass generation

→ is not RH, but some singlet from HS beside 3 ν_R

→ high mass scales are involved

A scheme

GUT scale

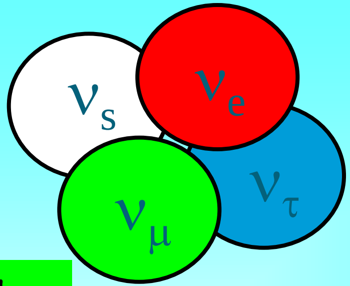


$M \sim M_{GUT} \sim 10^{16}$ GeV

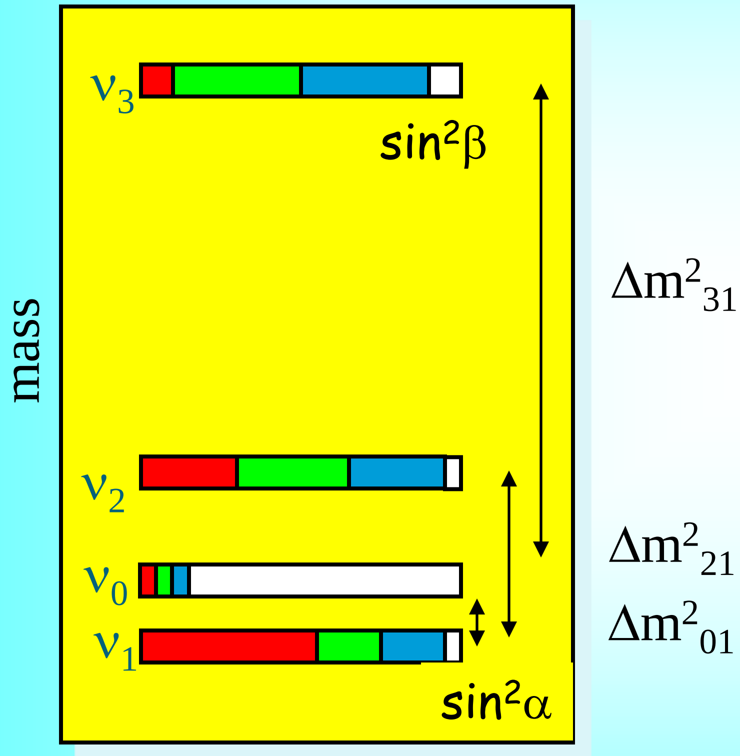
$m_D \sim m \sim 10^2$ GeV

$m_{aS} \sim m\, m_D / M$ $\sim 10^{-3}$ eV   Required mixing parameter

meV sterile neutrino



$m_0 \sim 0.003$ eV



For solar nu: $\sin^2 2\alpha \sim 10^{-3}$

For dark radiation

$\sin^2 2\beta \sim 10^{-3}$ (NH)

$\sin^2 2\beta \sim 10^{-1}$ (IH)

Motivated by

Solar neutrino data
- absence of upturn of spectrum

- additional radiation in the Universe if mixed in ν_3

no problem with LSS bound on neutrino mass

Origins:

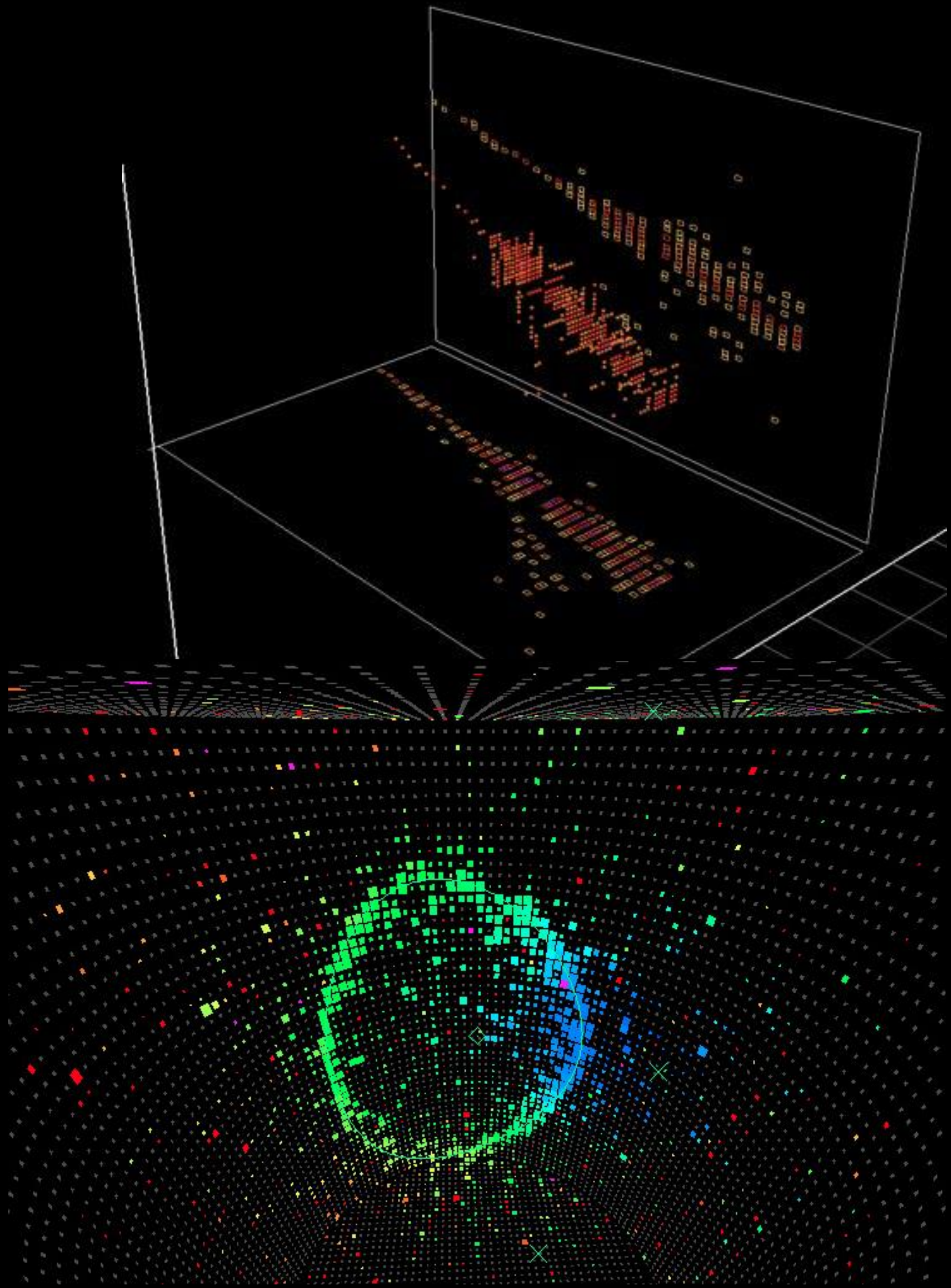
$$m_0 \sim \frac{M^2}{M_{Planck}}$$

$M \sim 2 - 3$ TeV

$\alpha, \beta \sim v / M$

In the Hidden sector?

Summary



Data support relation between l- and q- mixings $U_{PMNS} = V_{CKM}^{+} U_X$
Smallness of neutrino mass due to GUT-Planck scale physics – still appealing possibility

This implies unification of quarks and leptons and existence of new sector of theory which is responsible for smallness of neutrino mass and striking difference of mixing patterns.
This sector may have certain symmetries

The framework which allow to realise such a possibility considered and its properties are explored

The main elements of the framework:

- SO(10) type of Grand Unification,
- existence of the Hidden (singlet sector)
- Double (multiple) see-saw mechanism
- complete or partial screening on the Dirac structures
- existence of symmetries which ensure communication between hidden and visible sectors
- additional symmetries in the hidden sector

Hidden sector may contain many fermions and bosons which have their own symmetries as well as "basis fixing symmetry" which communicate information from hidden to visible sector in certain way. Basis fixing symmetry select only some components of the Hidden sector which immediately couple with visible one.

Certain features can appear due to involvement of many Components in hidden sector. Basis symmetry select only some of them

The framework allows to disentangle physics responsible for CKM and the one -- for special neutrino properties

Other manifestations of the Hidden sector can be

- sterile neutrinos
- certain values of CP phases
- dark matter

It can be related to leptogenesis , inflation, etc.