Physics beyond the Standard Model: Neutrinos & Dark matter

José W F Valle

http://astroparticles.ific.uv.es/

PASCOS 2013, Taiwan

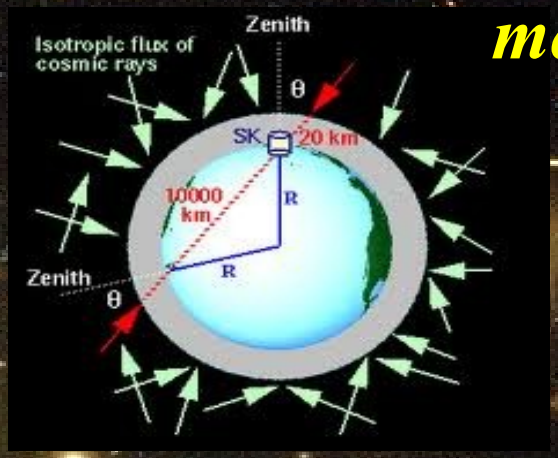
Where do neutrinos come from?

336 / cm3: bilions of

Cosmic neutrinos

Cross us every second

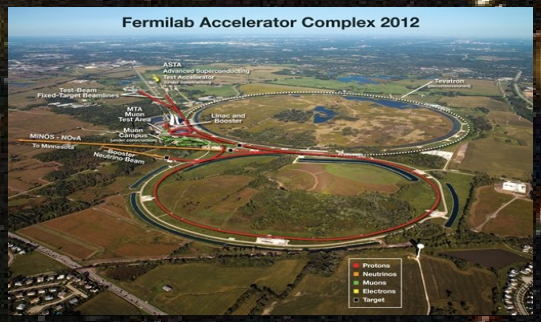
Necessary to revise Standard model



θ_{12}

θ_{23}

confirmation

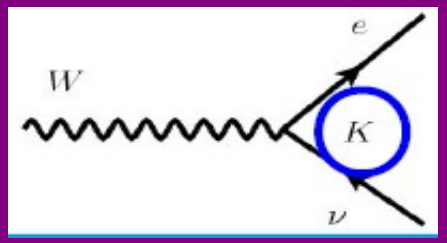


LEPTON MIXING MATRIX

$$K = \omega_{23} \cdot \omega_{13} \cdot \omega_{12}$$

Schechter & JV PRD22 (1980) 2227 & PDG

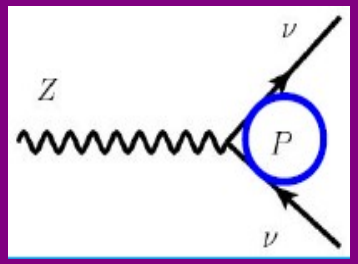
Rodejohann, JV Phys.Rev. D84 (2011) 073011

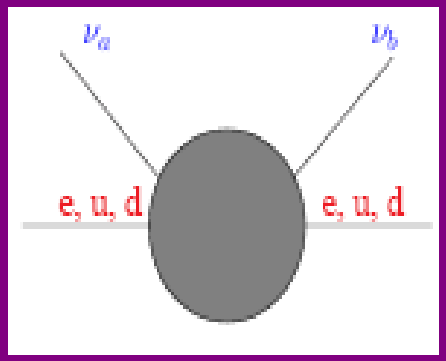


$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- Presence of **majorana phases (cf KM)**
- **Do not affect** (standard) **oscillations but** Crucial to describe L-violating processes

K Rectangular ⇒ **K_eff. non-unitary**
P Non-trivial
NSI & LFV



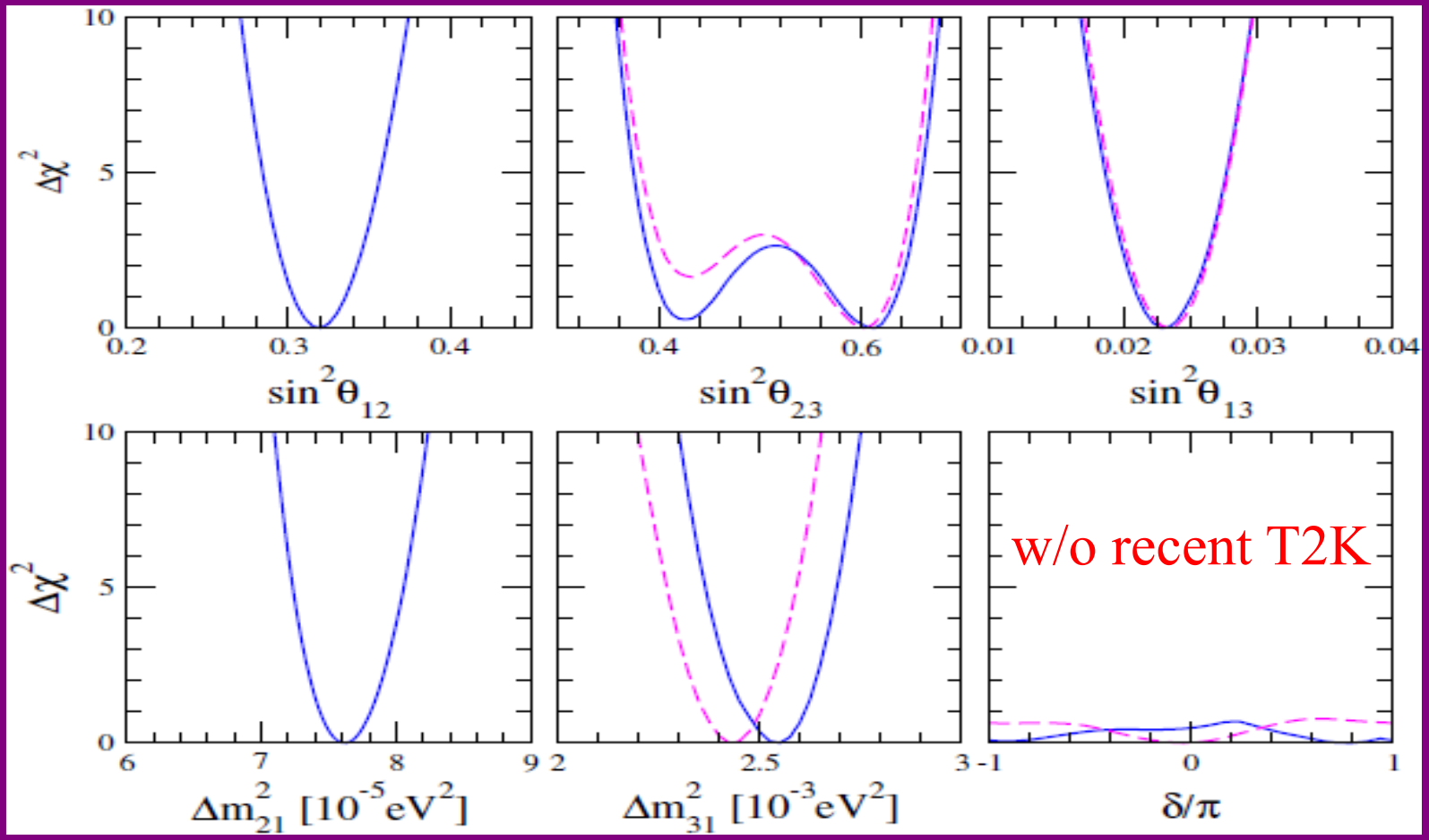


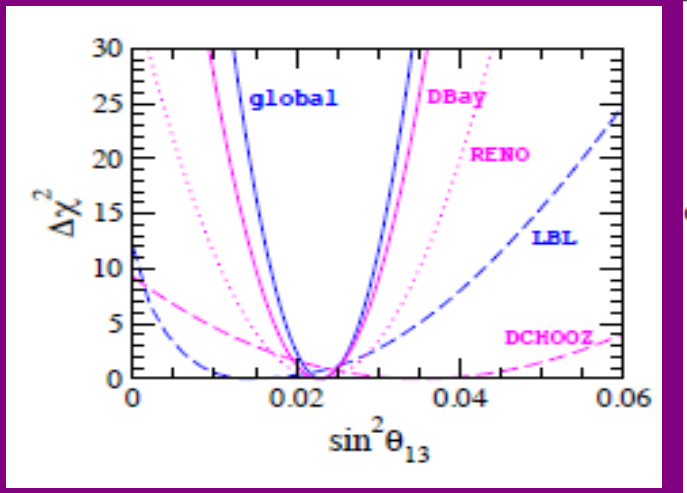
$$\begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

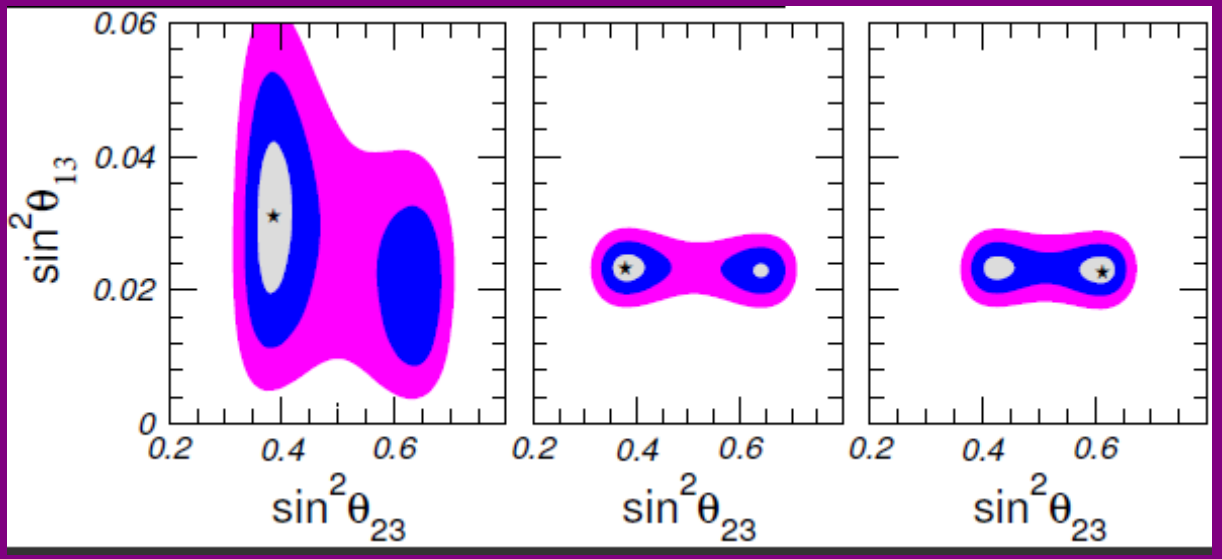
adopted in oscillation analyses

Oscillation parameters

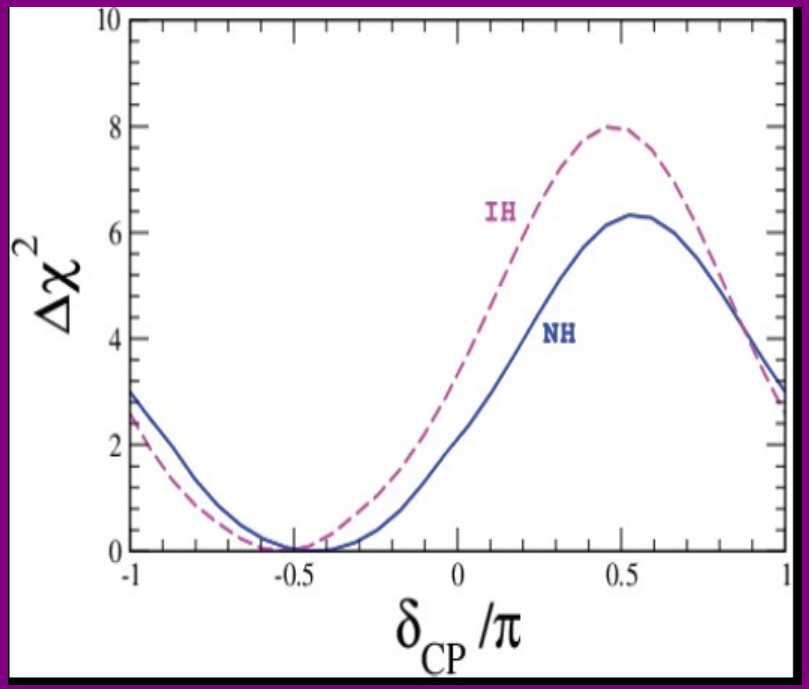
Preliminary 2013 update of
Phys. Rev. D 86, 073012 (2012)







Preliminary 2013



LBL+SOL+KL

+ REACTOR

+ ATM

arXiv:1310.6732 [hep-ex].

S. Seo's talk at TAUP 2013,

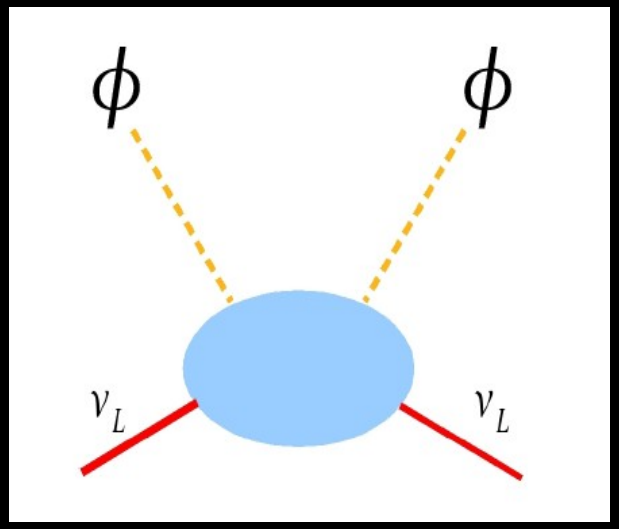
DayaBay 217-day

RENO 402-day

Courtesy of Tortola

non-trivial info on CP phase with new T2K result 1311.4750

ORIGIN OF NEUTRINO MASS & SEESAW



fermion exchange

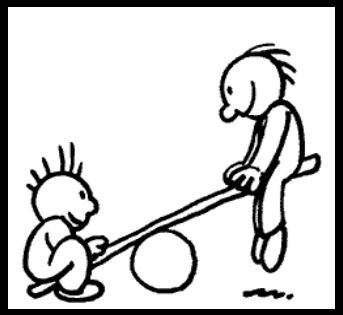
TYPE I

Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle, 80 & 82

Scalar-exchange

TYPE II

Schechter-Valle 80/82



$$v_3 v_1 \sim v_2^{\,2} \quad \text{with} \quad v_1 \gg v_2 \gg v_3$$

SCALE

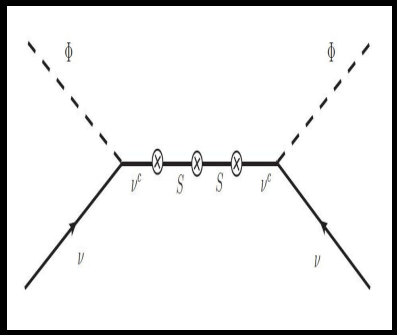
MECHANISM

FLAVOR STRUCTURE

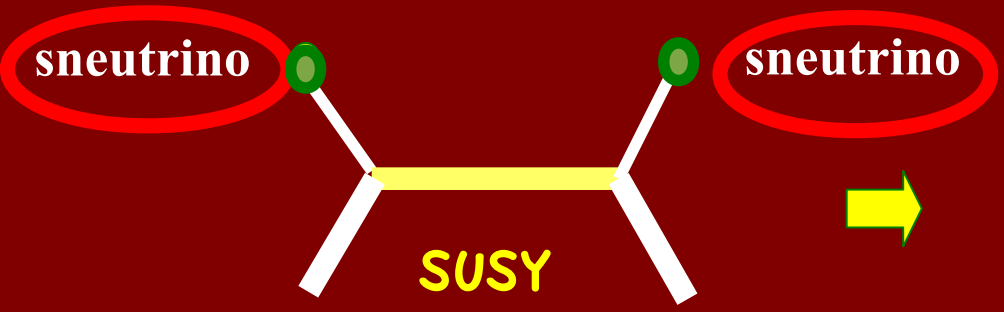
Number & gauge properties of messengers

LOW-SCALE SEESAW

Mohapatra-Valle 86
Akhmedov et al PRD53 (1996) 2752
Malinsky et al PRL95(2005)161801
Bazzocchi et al, PRD81 (2010) 051701



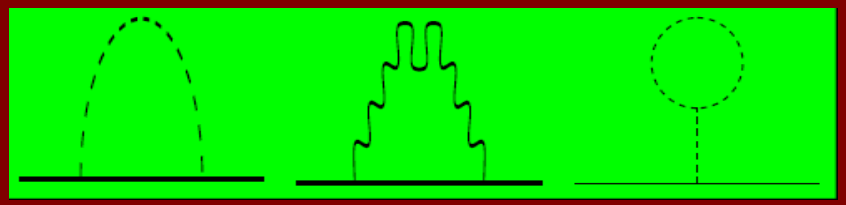
SUSY ORIGIN OF NEUTRINO MASS



Masiero & Valle, PLB251 (1990) 273
Bhattacharyya & Pal, PRD82 (2010) 055013

EFF. BILINEAR RPV

ATM SCALE
SUSY-SEESAW



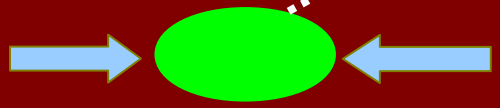
SOLAR SCALE
RADIATIVE

Diaz et al PRD68 (2003) 013009, PRD62 (2000) 113008
PRD65 (2002) 119901; PRD61 (2000) 071703
Bazzocchi et al JHEP 01 (2013) 033 arXiv:1202.1529

LIGHTEST NEUTRALINO DECAYS: PROBING NUs @ LHC

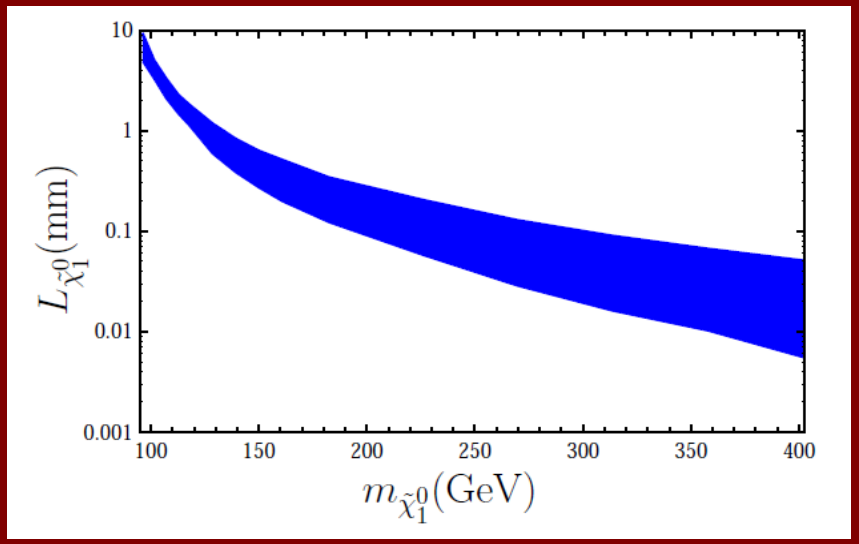
De Campos et al
Phys.Rev. D86 (2012) 075001
PRD82 (2010) 075002 &
JHEP 0805:048, 2008

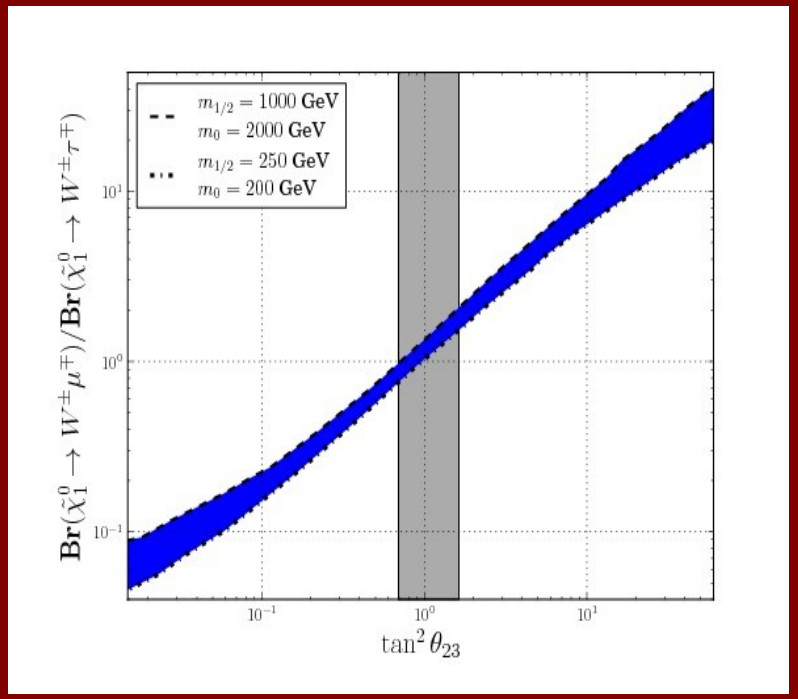
$$\tilde{\chi}_1^0 \to W^{\pm} l_i^{\mp} \qquad \tilde{\chi}_1^0 \to Z^0 \nu_i$$



Lightest neutralino decay correlates with atm angle

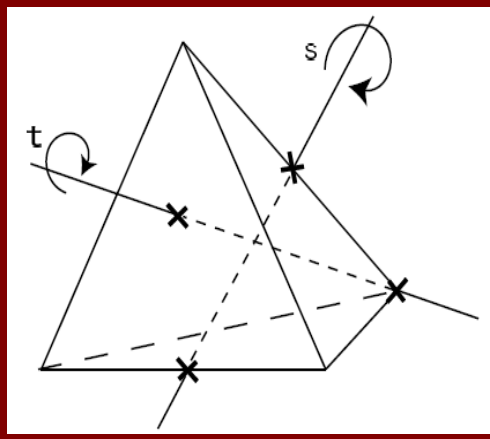
Lightest neutralino decay length





THE FLAVOR PROBLEM

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$$
$$e_R \qquad \mu_R \qquad \tau_R$$
$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \end{pmatrix}_L \quad \begin{pmatrix} t \\ b \end{pmatrix}_L$$
$$u_R \qquad c_R \qquad t_R$$
$$d_R \qquad s_R \qquad b_R$$



A4

Babu et al PLB552 (2003) 207
Hirsch et al PRD69 (2004) 093006

$$\sin^2\theta_{23} = 0.5$$

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

Tri-BiMaximal ansatz

Harrison, Perkins, Scott 2000

Altarelli, Feruglio 2005

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

$$U_{\rm TBM} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} & 0 \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & -\sqrt{\frac{1}{2}} \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & \sqrt{\frac{1}{2}} \end{pmatrix}$$

9

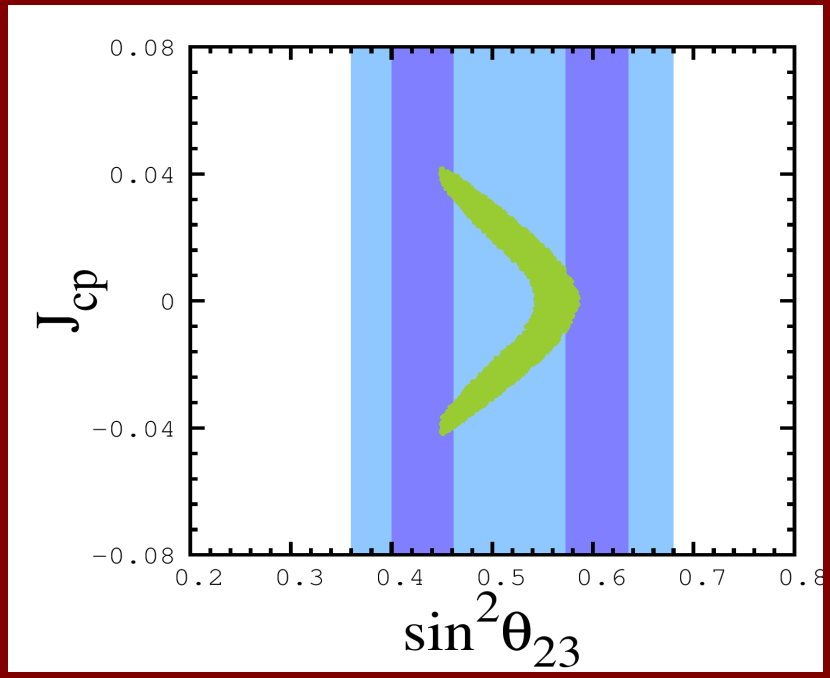
arXiv:1305.6774

PHYSICAL REVIEW D **88,** 016003 (2013)

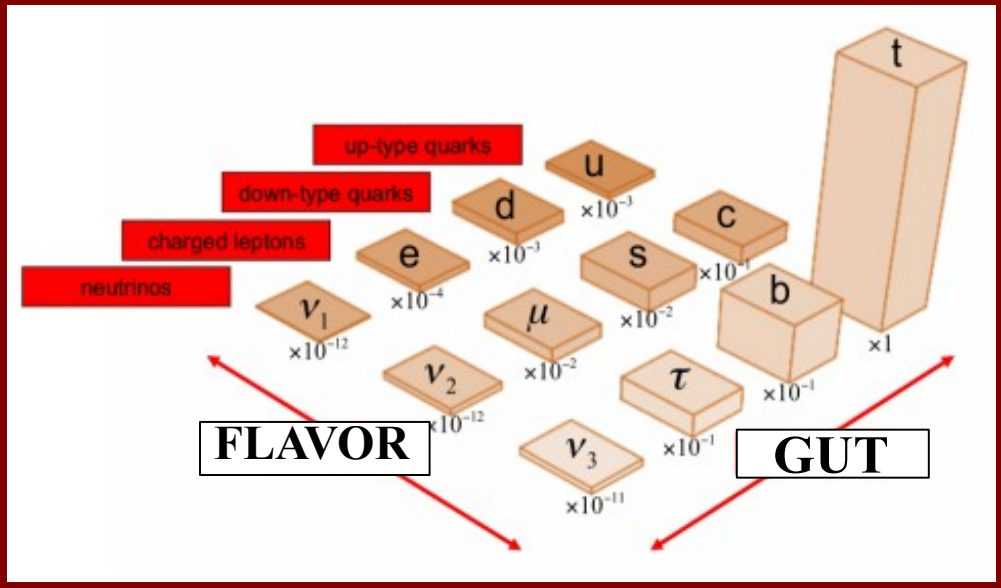
Neutrino mixing with revamped A_4 flavor symmetry

D. V. Forero,[1,2,*] S. Morisi,[3,†] J. C. Romão,[1,‡] and J. W. F. Valle[2,§]

STRIKING CORRELATION



A new way to relate Quarks to leptons?



PHYSICAL REVIEW D **84,** 036003 (2011)

Relating quarks and leptons without grand unification

S. Morisi,[1,*] E. Peinado,[1,†] Yusuke Shimizu,[2,‡] and J. W. F. Valle[1,§]

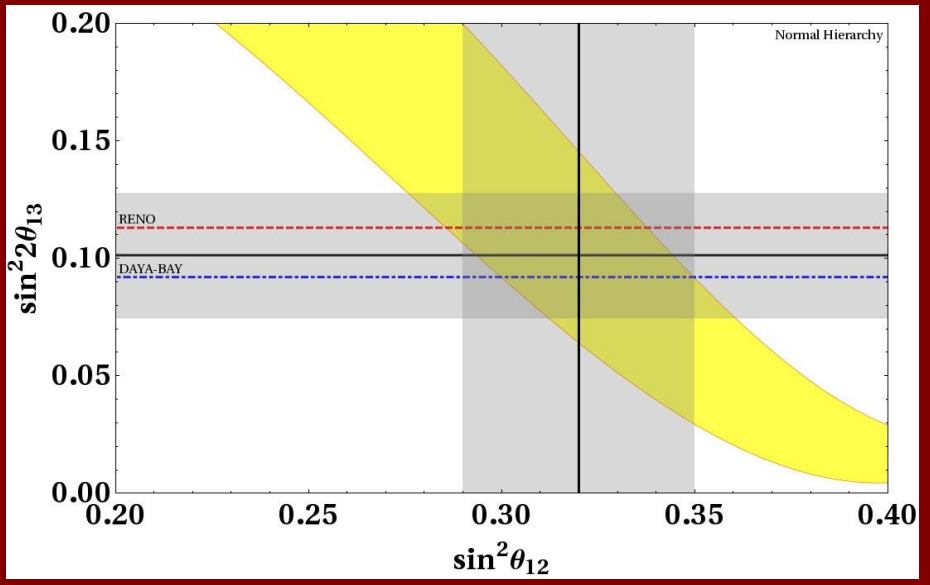
$$\frac{m_\tau}{\sqrt{m_e m_\mu}} \approx \frac{m_b}{\sqrt{m_d m_s}},$$

King et al **Phys. Lett. B 724 (2013) 68-72**

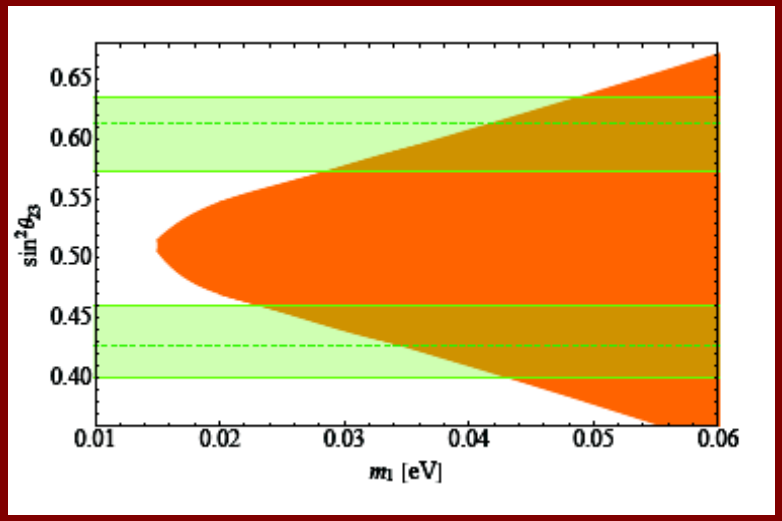
Morisi et al Phys.Rev. D88 (2013) 036001

OSCILLATION PARAMETER CORRELATIONS

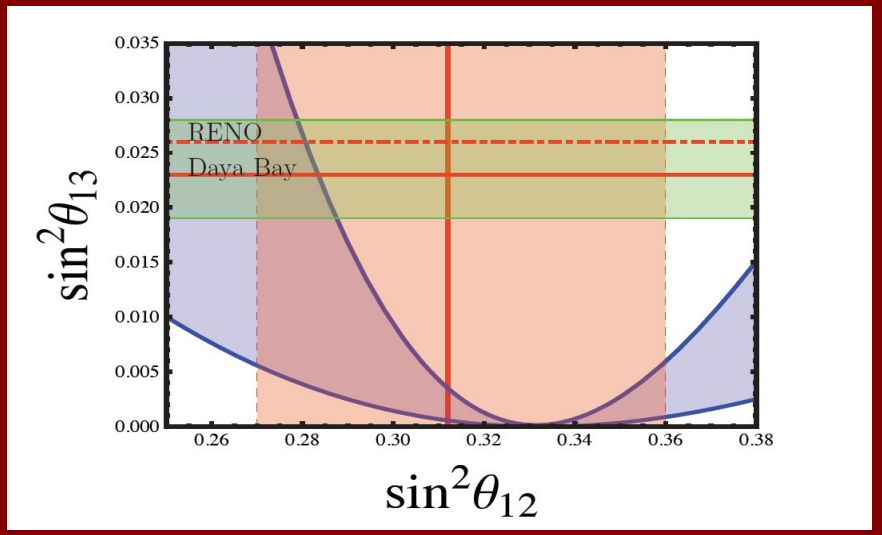
Boucenna et al
PhysRevD.86.073008



Phys. Lett. B 724 (2013) 68-72
King et al



Dorame, et al :



GFLAVOR

FLASY2011
FLASY2012
FLASY2013

Fortsch.Phys. 61 (2013) 466-492

DEVIATION OF TBM

Ishimori,etal Prog Theor Phys Suppl 183 (2010) 1

Nilles, Morisi, JV Z. fur Phys, 2012

Holthausen et al 1212.2411

CHANGE ANSATZ:

Albright,Dueck,Rodejohann 1004.2798

ANARCHY

Donoghue et al PRD73
Hall,Murayama,Weiner,PRL
Altarelli, Feruglio,Masina,JHEP

BI-LARGE

Boucenna,M,Tortola,Valle PRD86 (2012) 051301
Ding, Morisi, JV PRD (2013) 1211.6506 ...

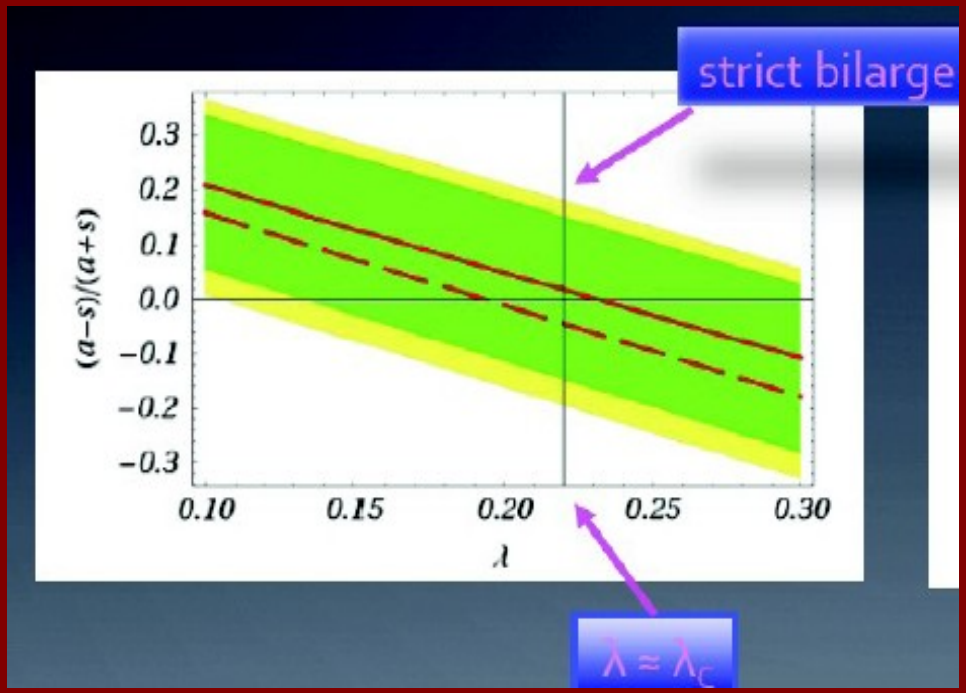
Bi-large mixing & Cabibbo angle

reactor seeds solar & atm

Boucenna et al, Phys. Rev. D 86, 051301(R)

$$\sin\theta_{13} = \lambda\,;$$
$$\sin\theta_{12} = s\,\lambda\,;$$
$$\sin\theta_{23} = a\,\lambda\,,$$

Ref.	λ	s	ϵ
Forero *et al.* [14]	0.23 ± 0.04	$2.8^{+0.5}_{-0.4}$	$0.067^{+0.035}_{-0.025}$
Fogli *et al.* [16]	$0.19^{+0.03}_{-0.02}$	$3.0^{+0.5}_{-0.3}$	$0.038^{+0.019}_{-0.018}$



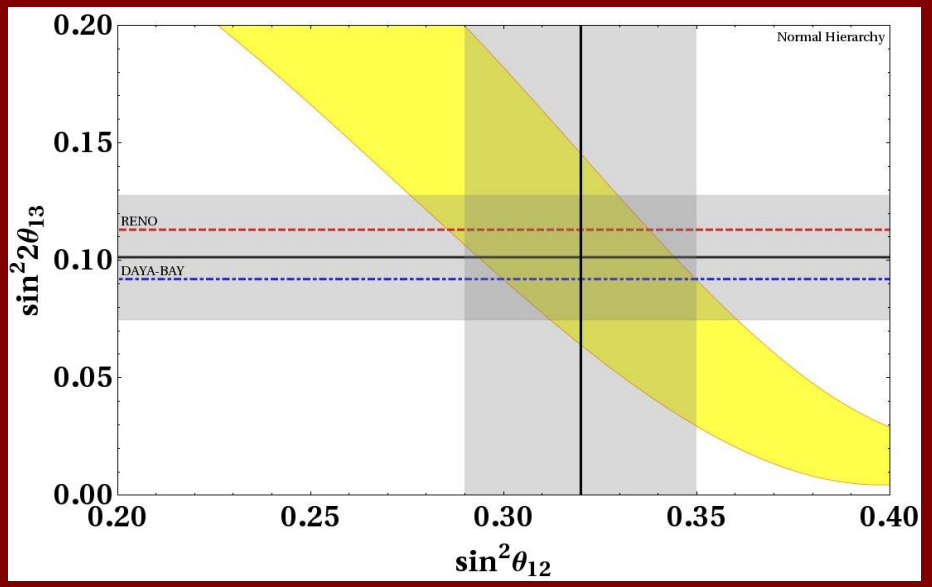
ABELIAN FLAVOR MODELS

Ding, et al Phys.Rev. D87 (2013) 053013

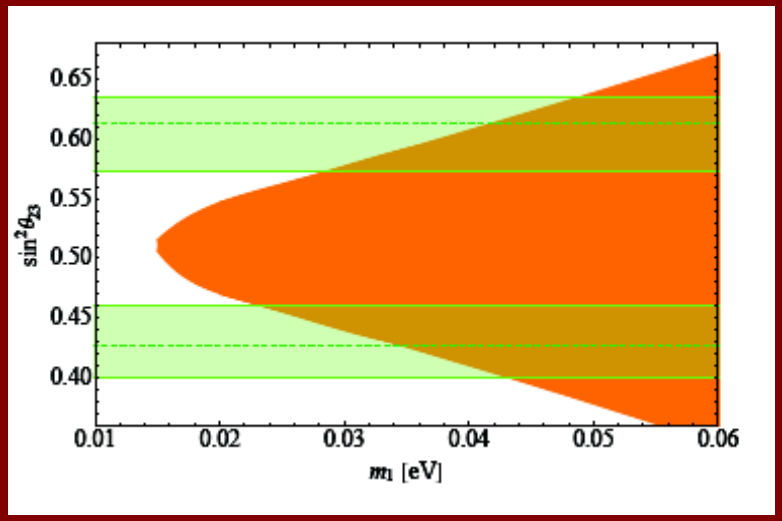
Roy, Singh, ..arXiv:1211.7207

OSCILLATION PARAMETER CORRELATIONS

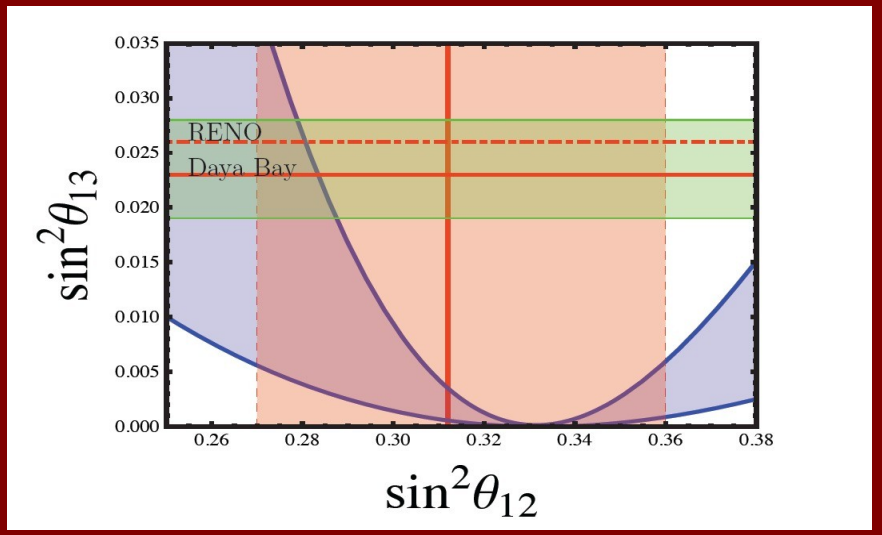
Boucenna et al
PhysRevD.86.073008



Phys. Lett. B 724 (2013) 68-72
King et al

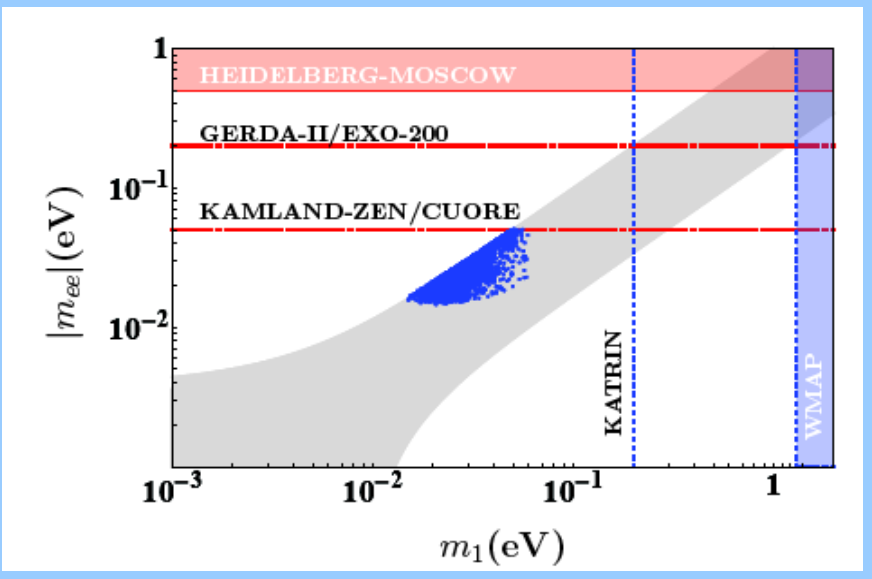


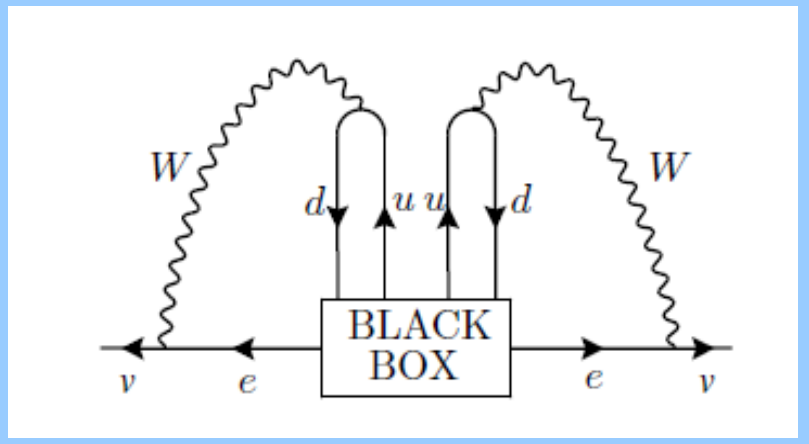
Dorame, et al :



TESTING NEUTRINO SPECTRA W/ NU-LESS Double Beta Decay

King et al : Phys. Lett. B 724 (2013) 68-72



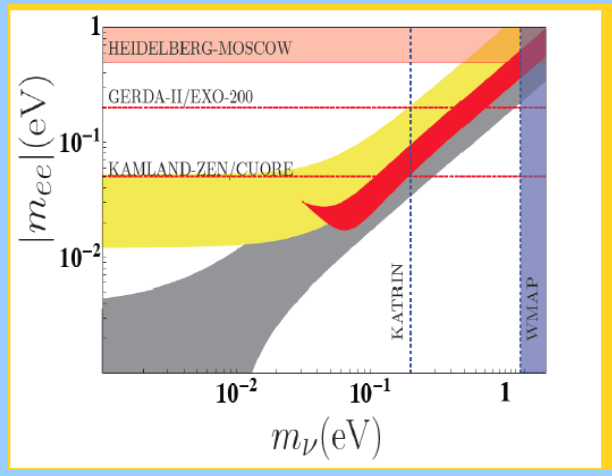


On the quantitative impact of the Schechter-Valle theorem

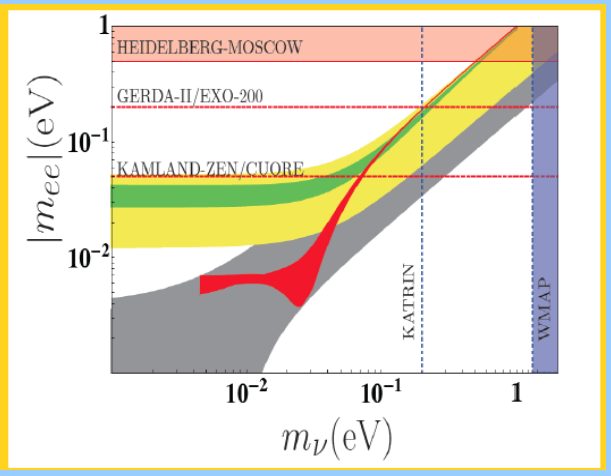
Michael Duerr,[a] Manfred Lindner[a] and Alexander Merle[a,b]

Flavor Sensitivity DBD lower bounds

Dorame et al
NPB861 (2012) 259-270



Dorame et al
PhysRevD.86.056001



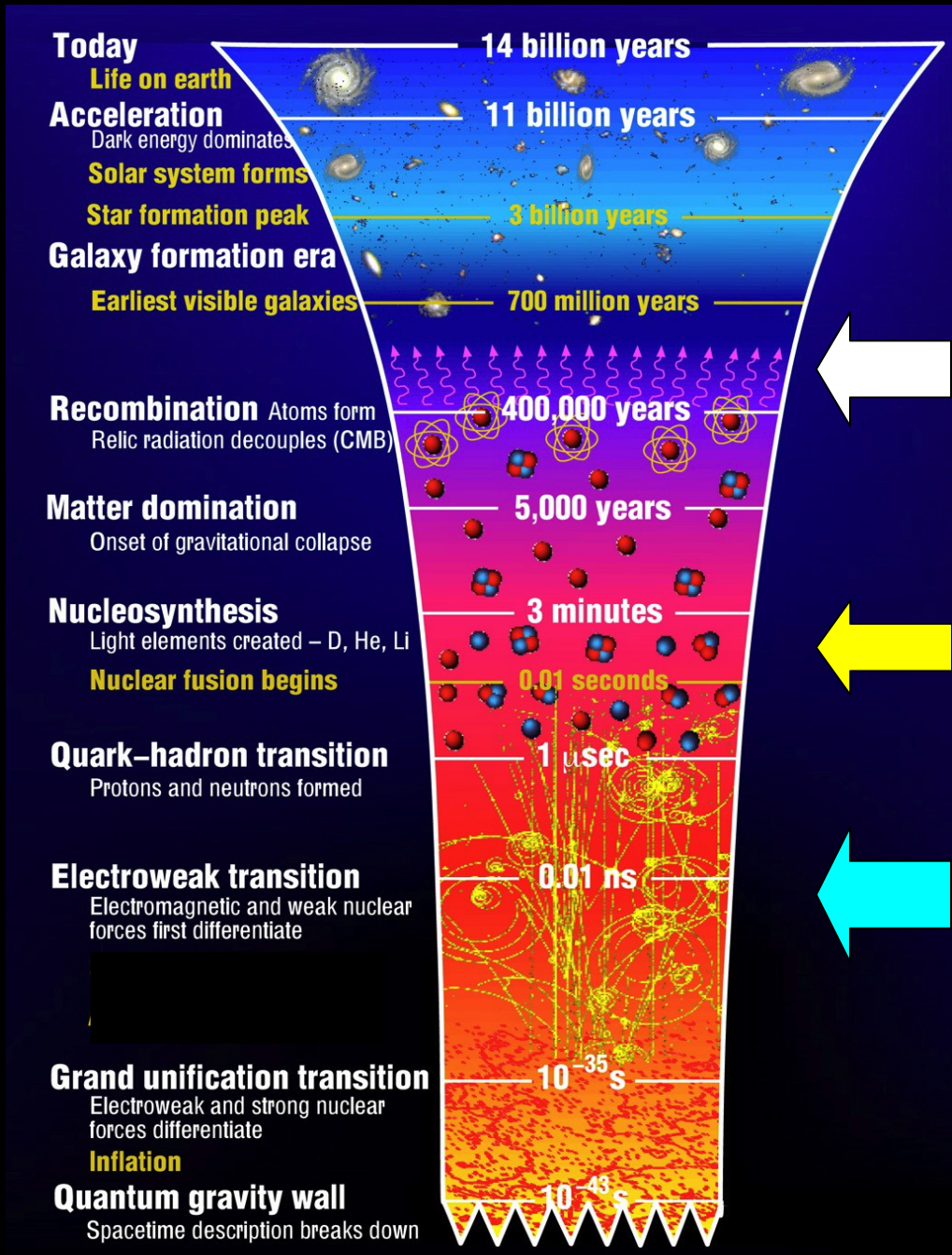
Neutrinos affect the CMB and large scale structure in the Universe …

are fundamental in the synthesis of light elements

can probe the Universe at much earlier epochs than photons …

explaining e.g. origin of dark matter ...

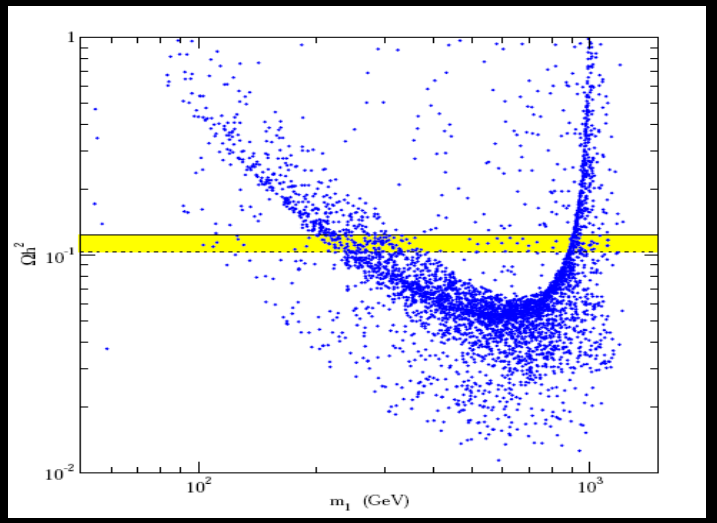
BIG-BANG



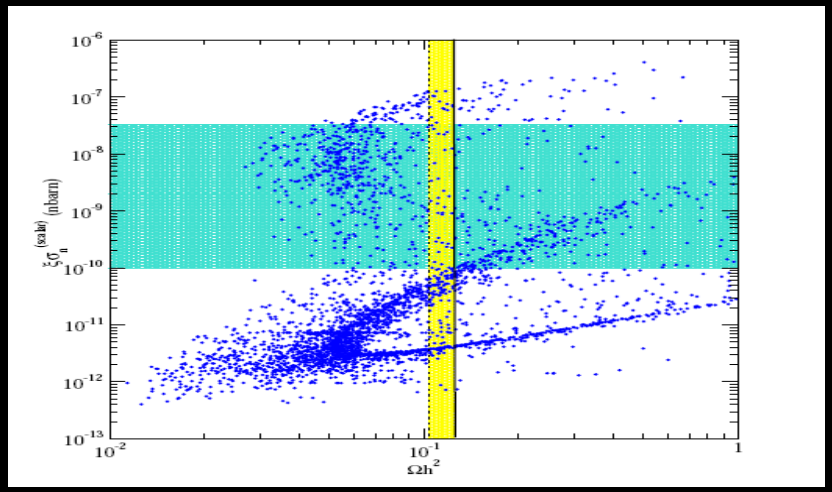
SNEUTRINO-like WIMP

instead of neutralino DM

Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701



Inverse seesaw susy spectrum



DM STABILITY ACCIDENT? Lavoura, Morisi, JV JHEP 1302(2013) 118

Stable Non-SUSY WIMP from FLAVOUR SYMMETRY

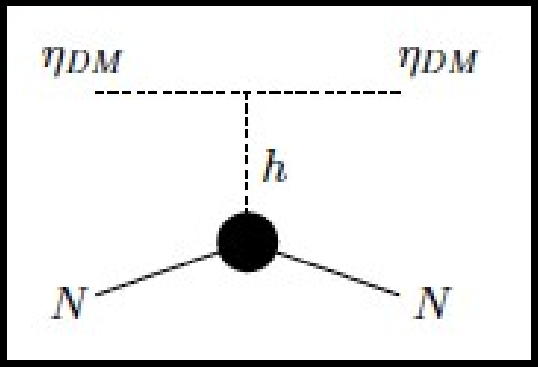
A4

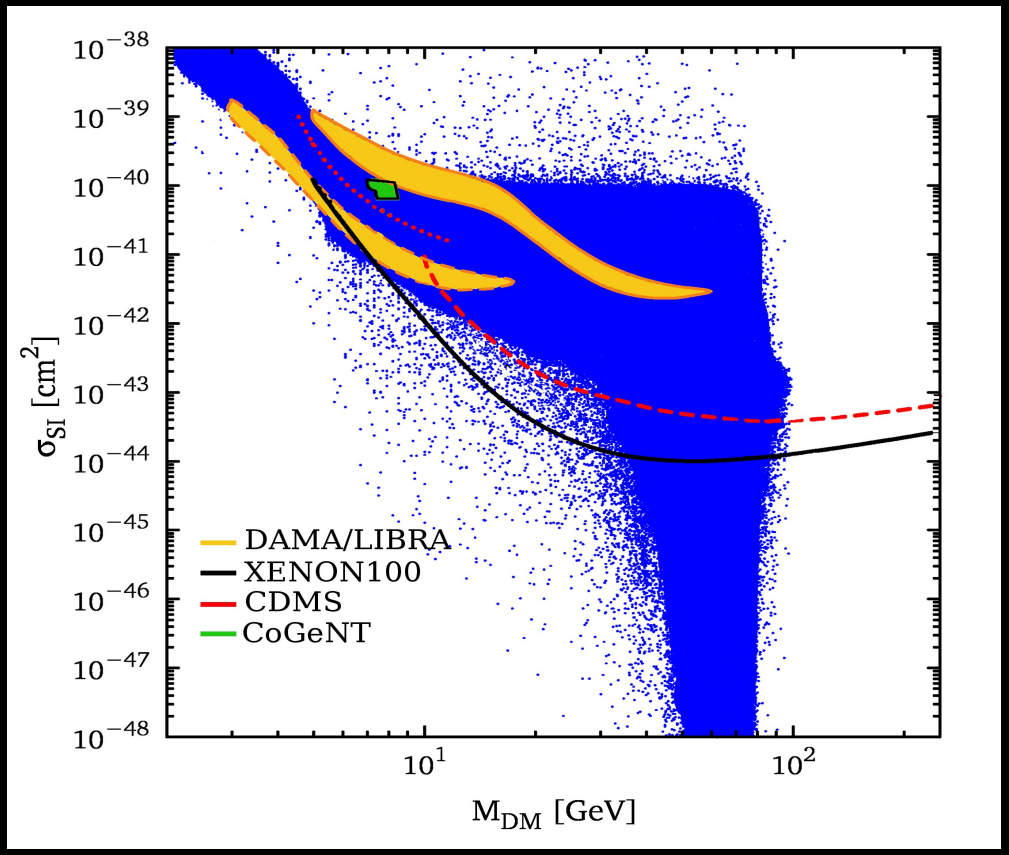
Hirsch, Morisi, Peinado, Valle
PRD82 116003 (2010)

Boucenna, Hirsch, Morisi, Peinado, Taoso, Valle JHEP 1105 037 (2011)

Z2 PARITY

HIGGS PORTAL DIRECT DETECTION



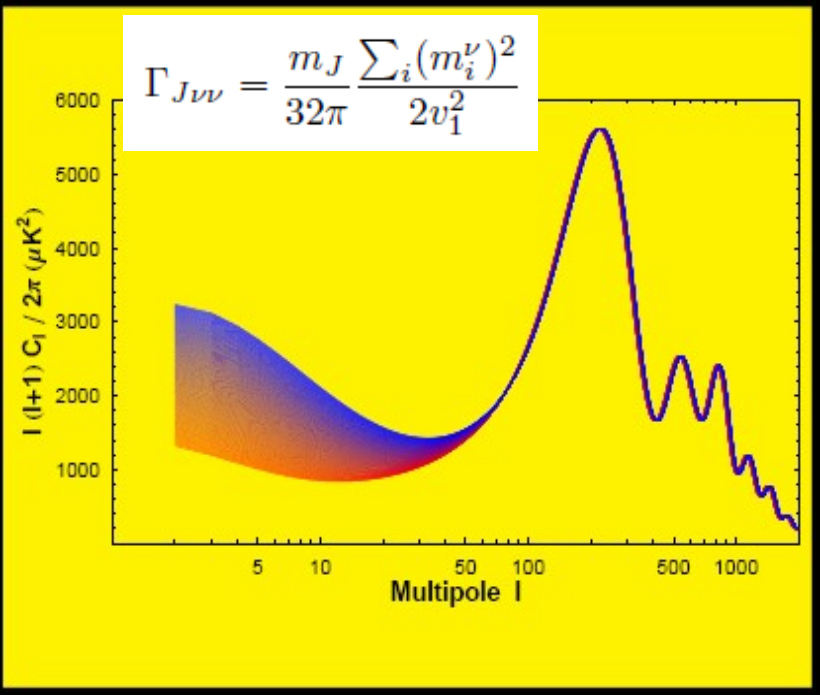


DARK MATTER MAJORONS

Berezinsky, Valle PLB318 (1993) 360

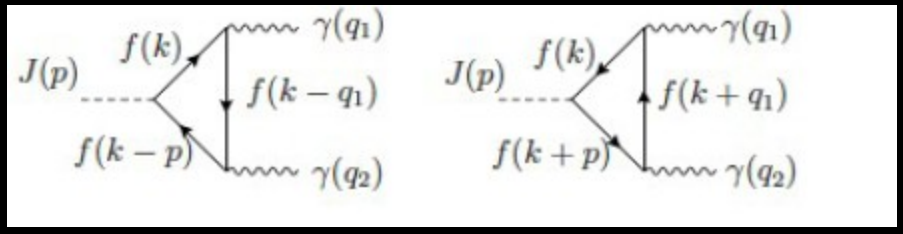
Consistency with CMB

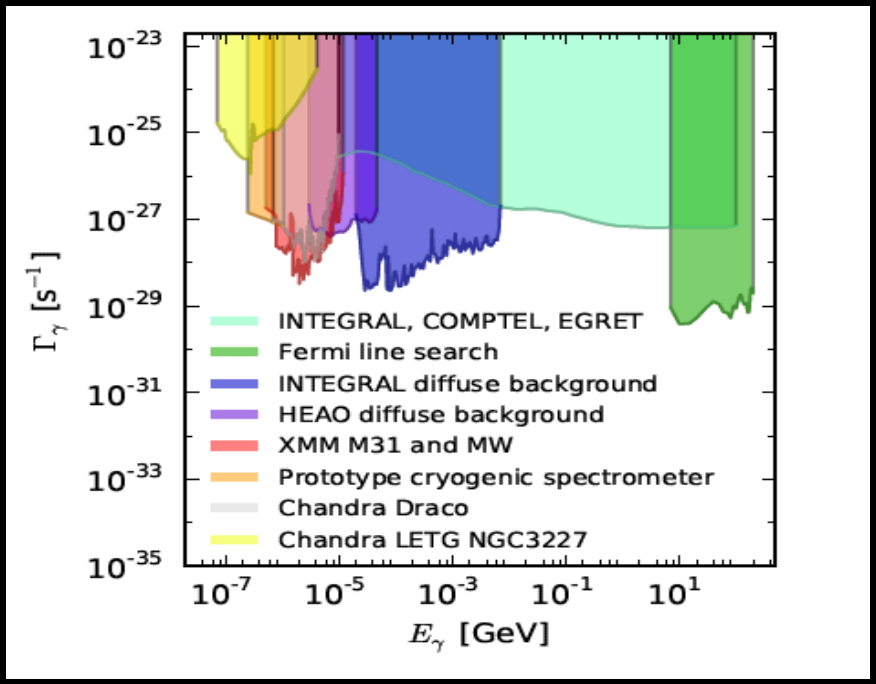
Lattanzi & Valle, PRL99 (2007) 121301



Esteves et al, PRD 82, 073008 (2010)

Bazzocchi & al JCAP 0808 (2008) 013





Lattanzi et al PRD88 (2013) 063528

Gamma line from decaying Gravitino dark matter

decays suppressed by Planck mass & smallness of m-nu

$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

chosen to fit neutrino osc. data

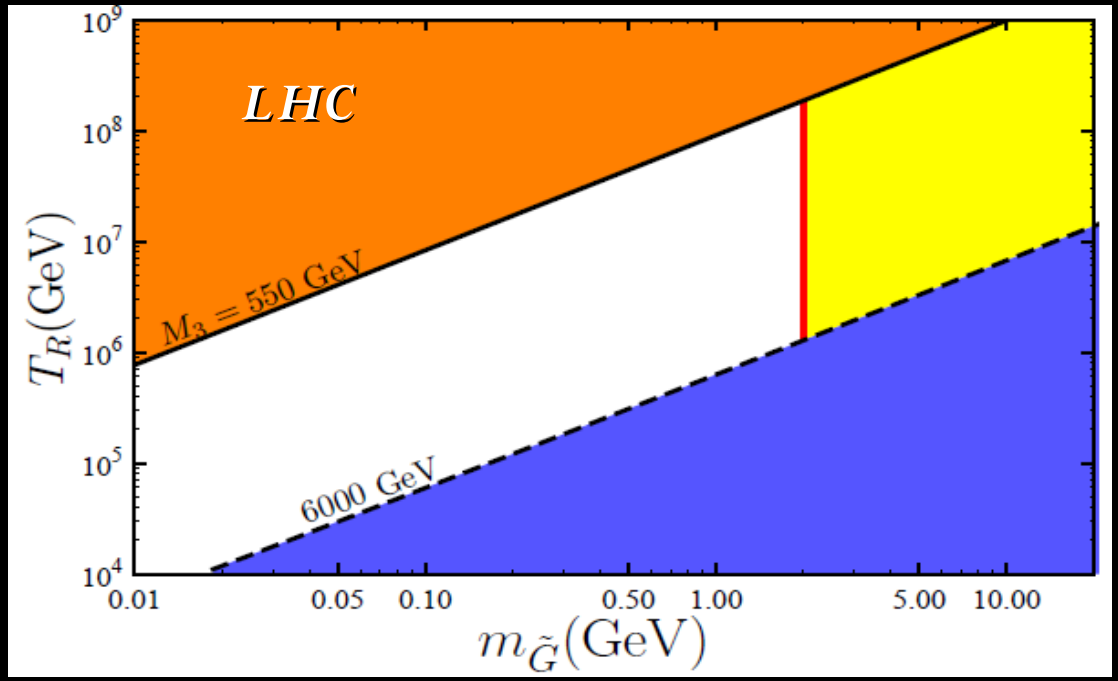
Restrepo et al
PRD85 (2012) 023523

relic abundance

+ LHC searches

excluded by gamma line searches @

Egret & Fermi-LAT



OSCILLATIONS ROBUST … PHASE, **SPECTRUM, OCTANT, NSI ?**

ORIGIN OF NEUTRINO MASS : which **MESSENGER?**

NEUTRINO PROPERTIES : TESTABLE @ LHC ?

FLAVOR PATTERN: anarchy or **SYMMETRY?**

DARK MATTER relates to **NEUTRINOS?**

DARK MATTER why **STABLE?** **NON-SUSY WIMP?**

MAJORON & **GRAVITINO** as **DECAYING DARK MATTER?**

謝謝