Neutrino mass status and outlook

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

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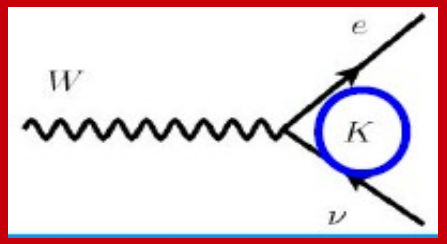
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

LEPTON MIXING MATRIX

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

Schechter & JV PRD22 (1980) 2227 & PDG

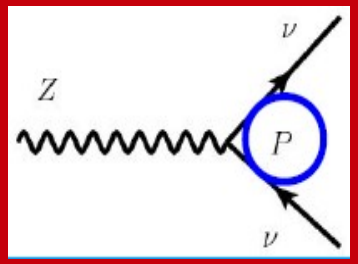
Rodejohann, JV Phys.Rev. D84 (2011) 073011

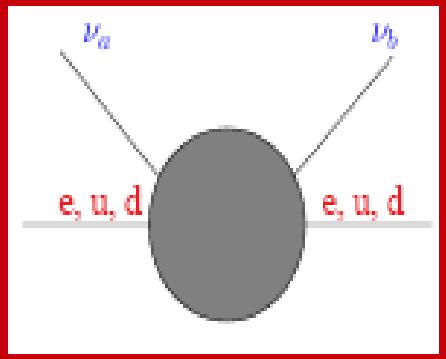


$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}}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

- 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 effects



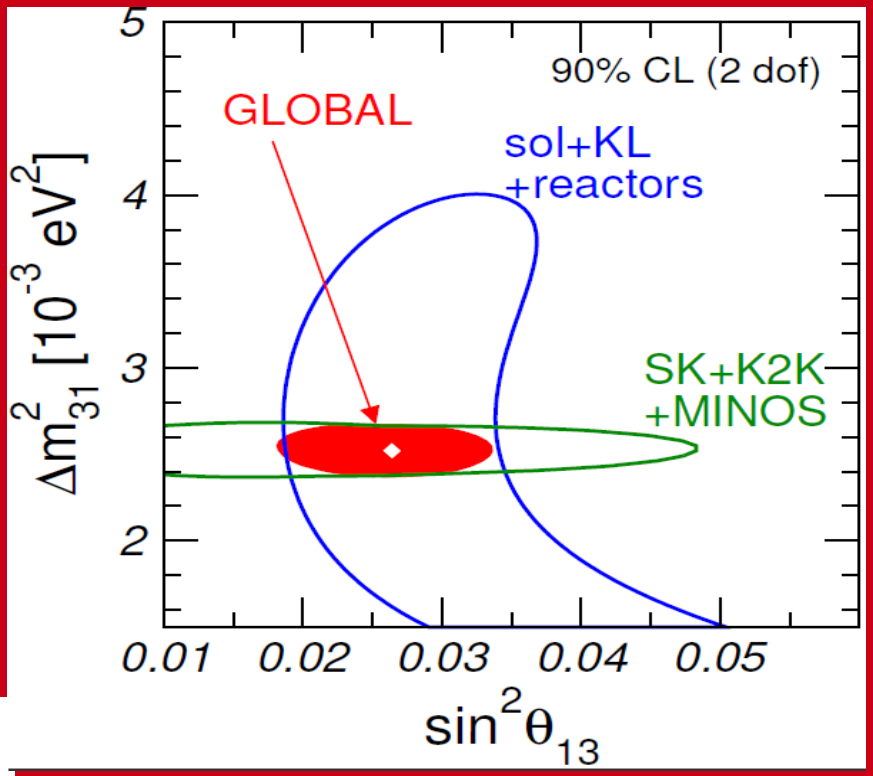


$$\begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

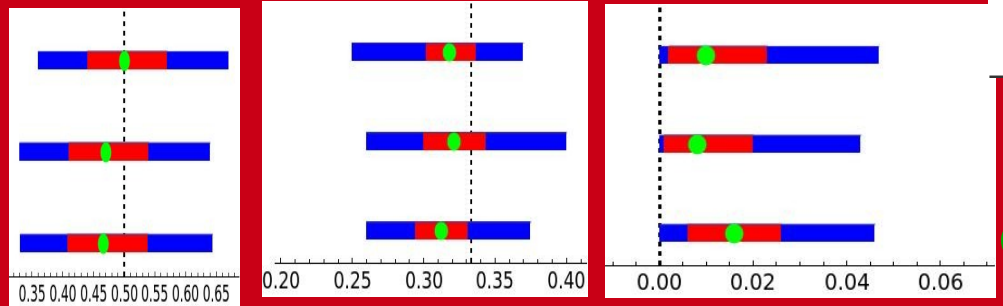
adopted in oscillation analyses

oscillation parameters



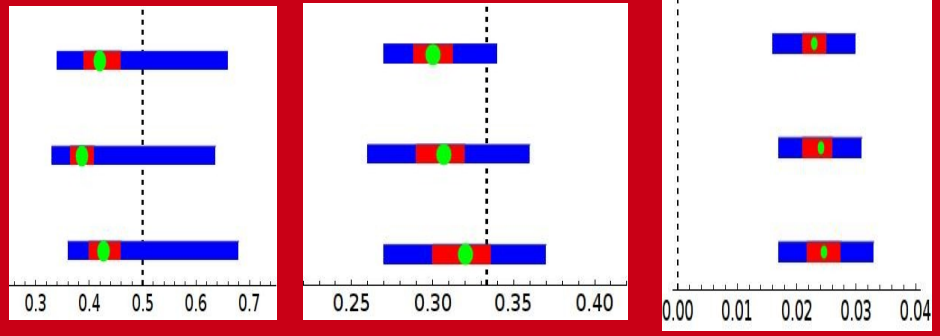


1/2 **1/3** **0**



2011

$\sin^2\theta_{13}$



2012

Schwetz Tortola & JV
Forero, Tortola et al
Gonzalez-Garcia et al

Fogli et al

PHYSICAL REVIEW D 86, 073012 (2012)

Global status of neutrino oscillation parameters after Neutrino-2012

D. V. Forero,* M. Tórtola,† and J. W. F. Valle‡

AHEP Group, Instituto de Física Corpuscular - C.S.I.C./Universitat de València Edificio de Institutos de Paterna, Apartado 22085, E-46071 València, Spain

(Received 18 May 2012; published 18 October 2012)

Here we update the global fit of neutrino oscillations in Refs. [T. Schwetz, M. Tortola, and J. W. F. Valle, New J. Phys. **13**, 063004 (2011); T. Schwetz, M. Tortola, and J. W. F. Valle, New J. Phys. **13**, 109401 (2011)] including the recent measurements of reactor antineutrino disappearance reported by the Double Chooz, Daya Bay, and RENO experiments, together with latest MINOS and T2K appearance and disappearance results, as presented at the Neutrino-2012 conference. We find that the preferred global fit value of θ_{13} is quite large: $\sin^2\theta_{13} \simeq 0.025$ for normal and inverted neutrino mass ordering, with $\theta_{13} = 0$ now excluded at more than 10σ. The impact of the new θ_{13} measurements over the other neutrino oscillation parameters is discussed as well as the role of the new long-baseline neutrino data and the atmospheric neutrino analysis in the determination of a non-maximal atmospheric angle θ_{23}.

DOI: 10.1103/PhysRevD.86.073012 PACS numbers: 14.60.Pq, 12.15.Ff, 13.15.+g, 26.65.+t

"LARGE" THETA 13

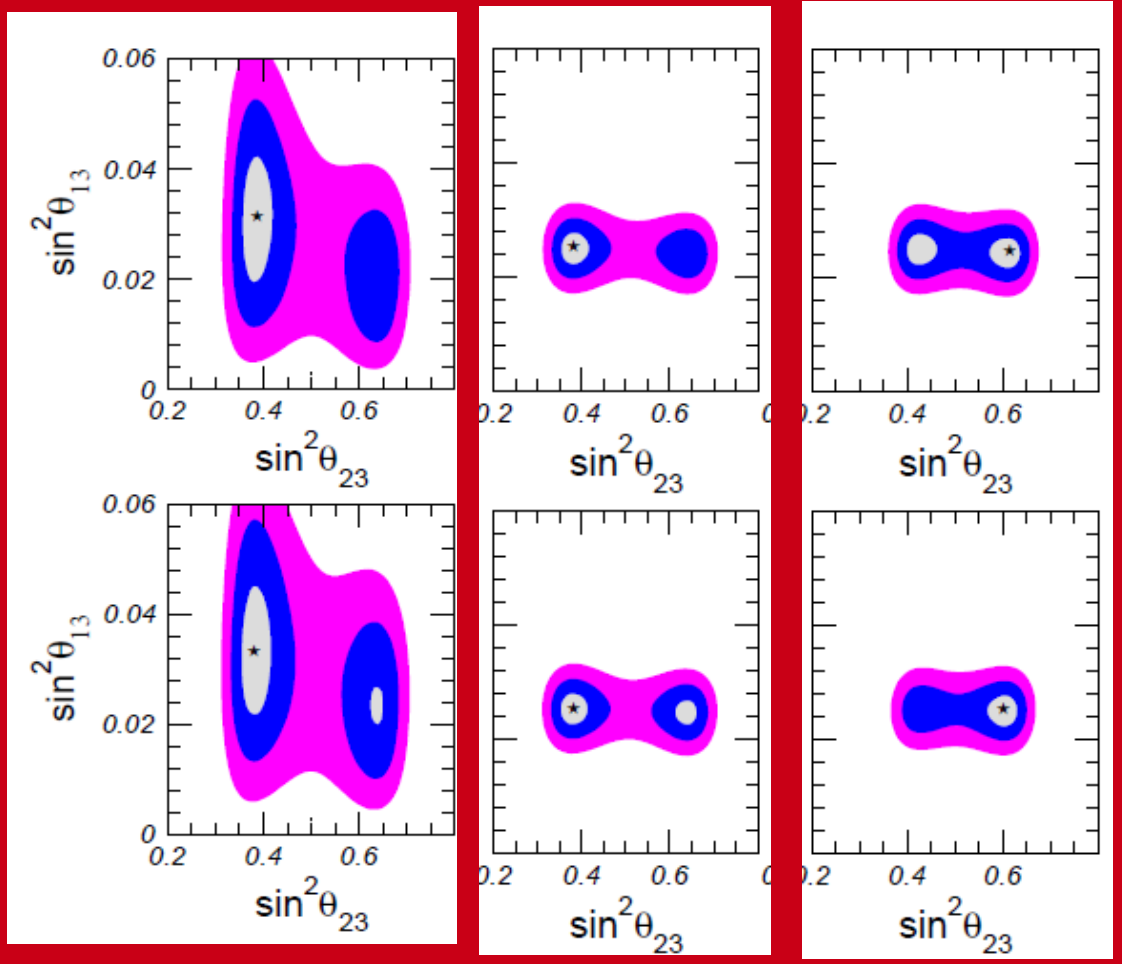
$$\sin^2\theta_{13} = 0.0246^{+0.0029}_{-0.0028}, \quad \Delta\chi^2 = 103.5 (10.2\sigma)$$

H. Nunokawa et al. / Progress in Particle and Nuclear Physics 60 (2008) 338–402

IOP PUBLISHING REPORTS ON PROGRESS IN PHYSICS

Rep. Prog. Phys. 72 (2009) 106201 (185pp) doi:10.1088/0034-4885/72/10/106201

THETA 23



LBL+SL+KL

LBL+SL+KL

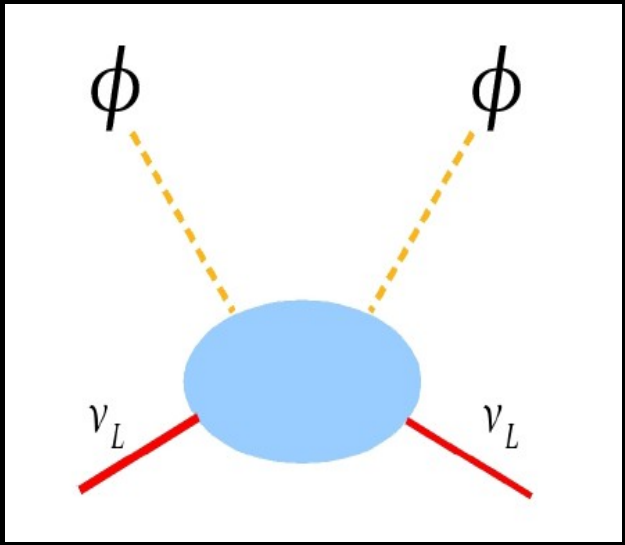
REACTOR

LBL+SL+KL

REACTOR

ATM

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

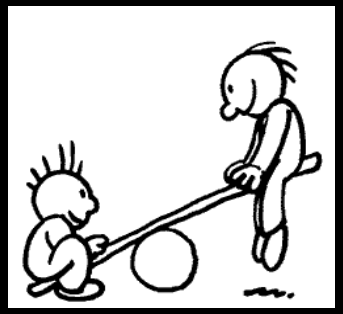
TYPE II

Schechter-Valle 80/82

SCALE

MECHANISM

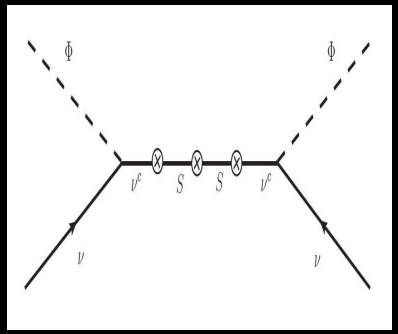
FLAVOR STRUCTURE



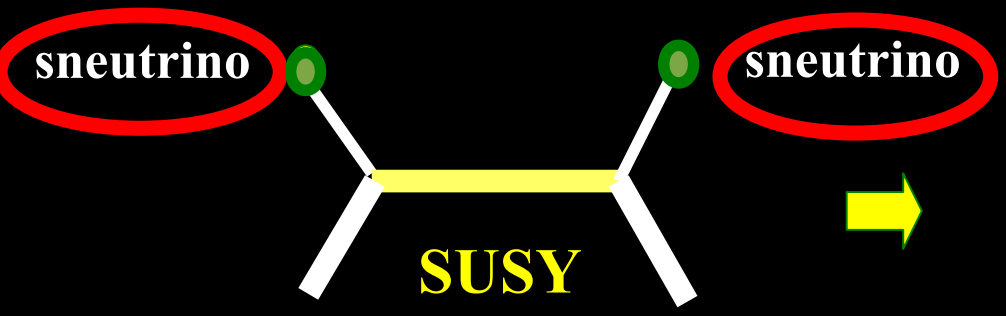
$$v_3 v_1 \sim v_2^{\,2} \quad \text{with} \quad v_1 \gg v_2 \gg v_3$$

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 NU-MASS

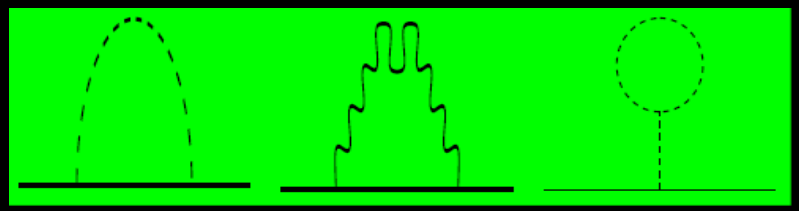


Masiero & Valle, PLB251 (1990) 273
Bhattacharyya & Pal, PRD82 (2010) 055013

EFF. BILINEAR RPV

ATM SCALE
SUSY-SEESAW

Hall & Suzuki,
Ross & JV 85, Ellis et al 85, ..



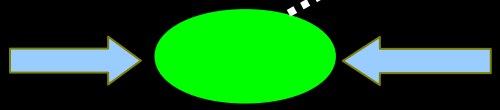
SOLAR SCALE
RADIATIVE

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

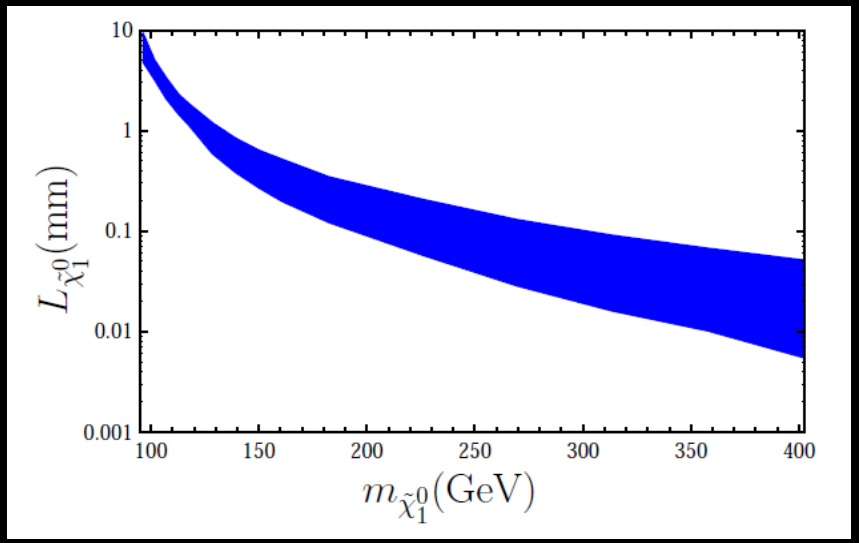
NEUTRALINO DECAYS: PROBING NUs @ LHC

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

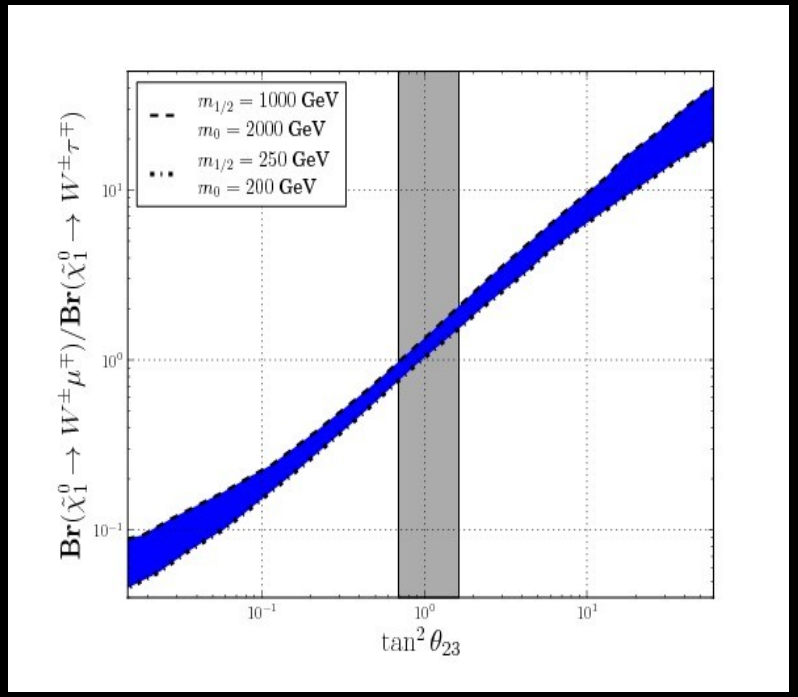
$$\tilde{\chi}_1^0 \to W^{\pm} l_i^{\mp} \qquad \tilde{\chi}_1^0 \to Z^0 \nu_i$$



Lightest neutralino decay length

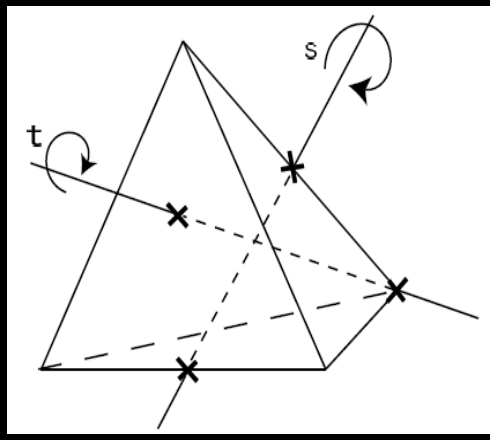


Lightest neutralino decay correlates with atm angle



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

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

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

Harrison, Perkins, Scott
Altarelli, Feruglio

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

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

FLASY2011
FLASY2012
FLASY2013

Deviation of TBM

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

Nilles, Morisi, JV Z. fur Phys, 2012

Holthausen et al 1212.2411

Different ansatz:

trimaximal, tetramaximal, symmetric & hexagon mixing, bimaximal, golden,..

Albright,Dueck,Rodejohann 1004.2798

Bi-Trimaximal

King, Luhn, Stuart 1207.5741

Anarchy

Hall,Murayama,Weiner,PRL
Altarelli, Feruglio,Masina,JHEP

BI-LARGE

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

Neutrino mixing with revamped A4 flavour symmetry

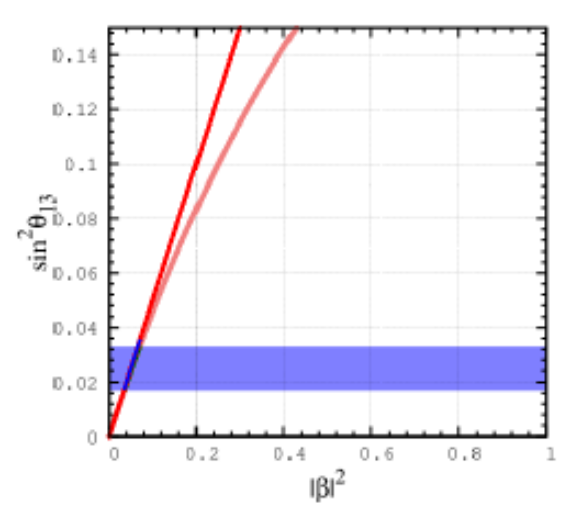
S. Morisi,[1,*] D. V. Forero,[2,†] J. C. Romão,[2,‡] and J. W. F. Valle[3,§]

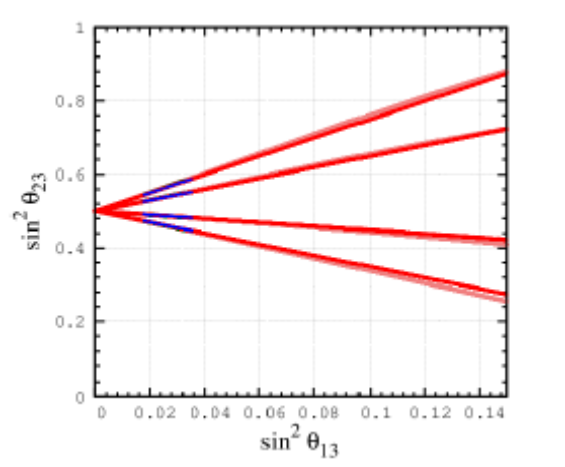
[1] *Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany*

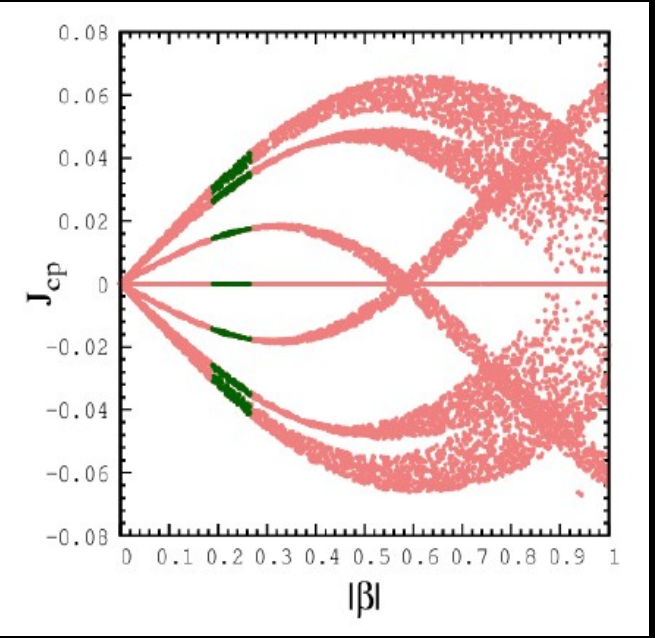
[2] *Departamento de Física and CFTP, Instituto Superior Técnico Technical University of Lisbon,1049-001 Lisboa, Portugal*

[31] *AHEP Group, Institut de Física Corpuscular – C.S.I.C./Universitat de València Edificio Institutos de Paterna, Apt 22085, E–46071 Valencia, Spain*

(Dated: May 18, 2013)





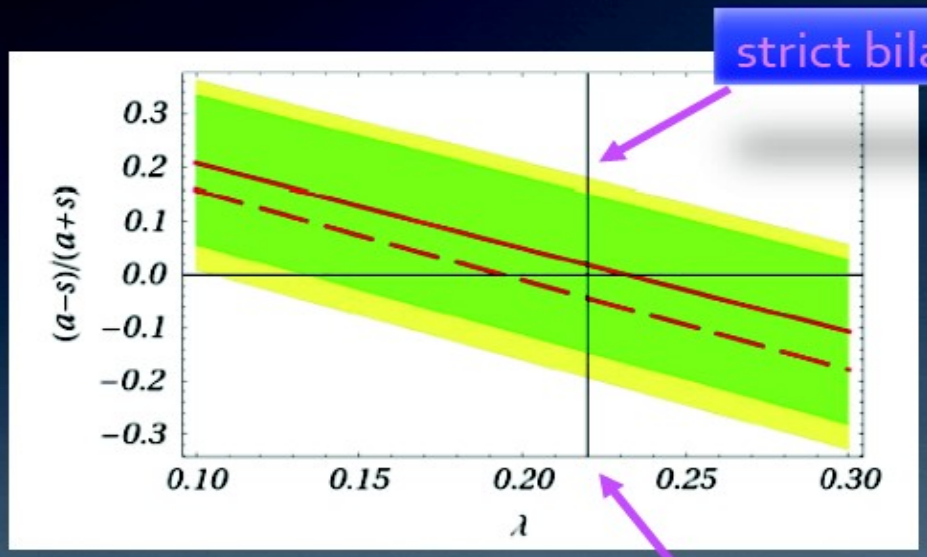


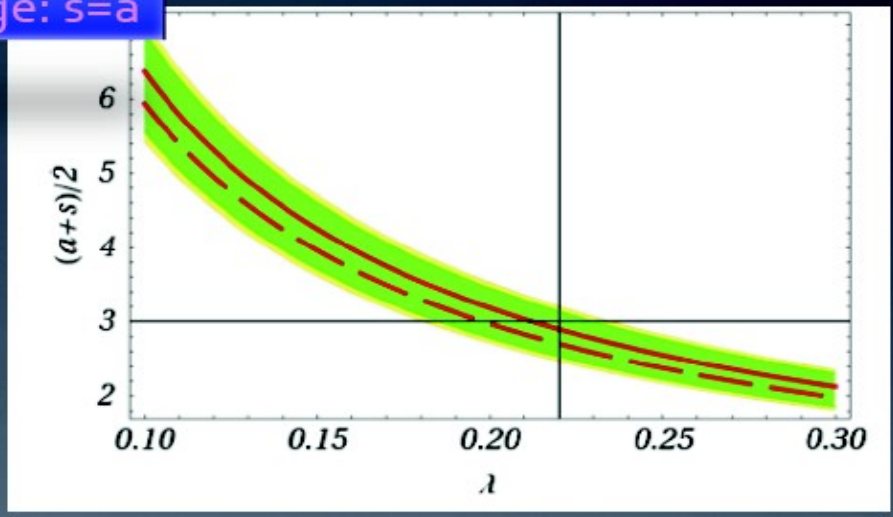
Bi-large instead of TBM *(after MINOS, Daya-Bay, etc)*

reactor seeds solar & atm Boucenna et al http://prd.aps.org/abstract/PRD/v86/i5/e051301

$$\sin^2\theta_{13} = \lambda$$
$$\sin^2\theta_{12} = s\lambda$$
$$\sin^2\theta_{23} = a\lambda$$

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]	$0.19^{+0.03}_{-0.02}$	$3.0^{+0.5}_{-0.3}$	$0.038^{+0.019}_{-0.018}$

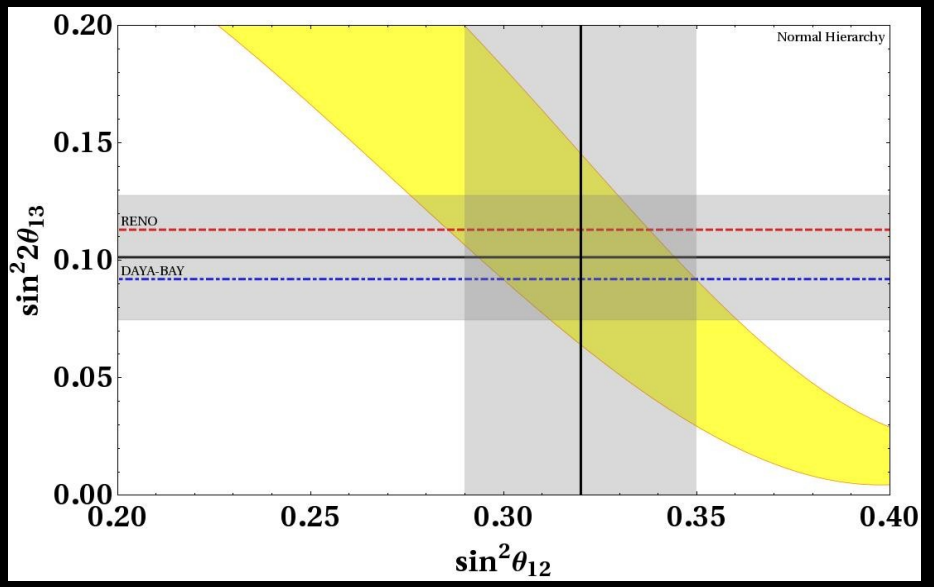




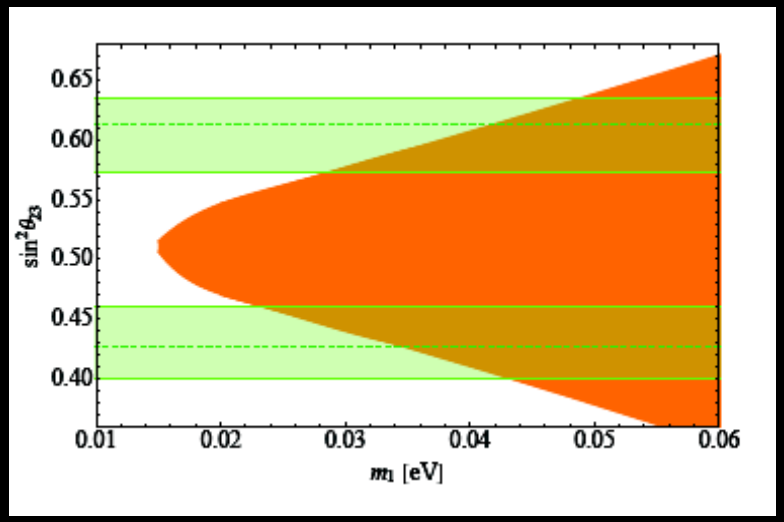
Models Ding et al http://prd.aps.org/abstract/PRD/v87/i5/e053013 Roy, Singh, ...

OSCILLATION PARAMETER CORRELATIONS

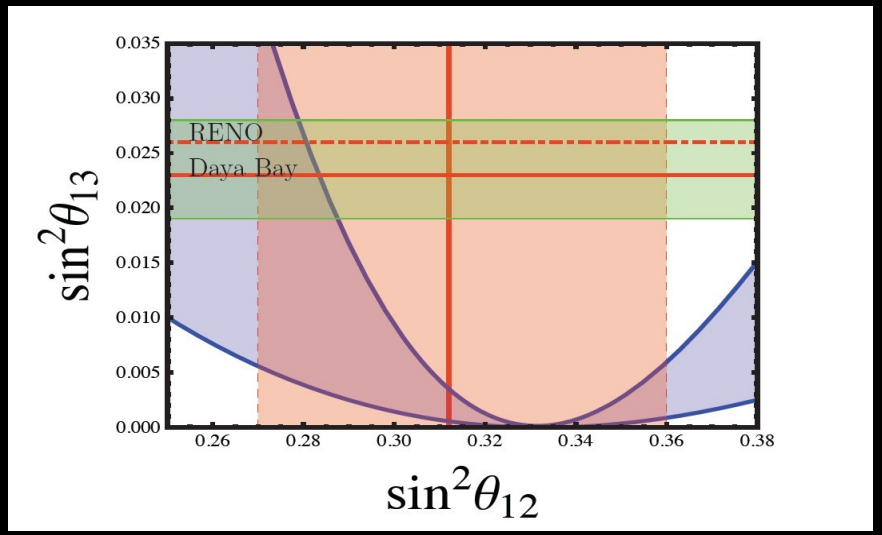
Dorame, et al :
10.1103/PhysRevD.86.056001

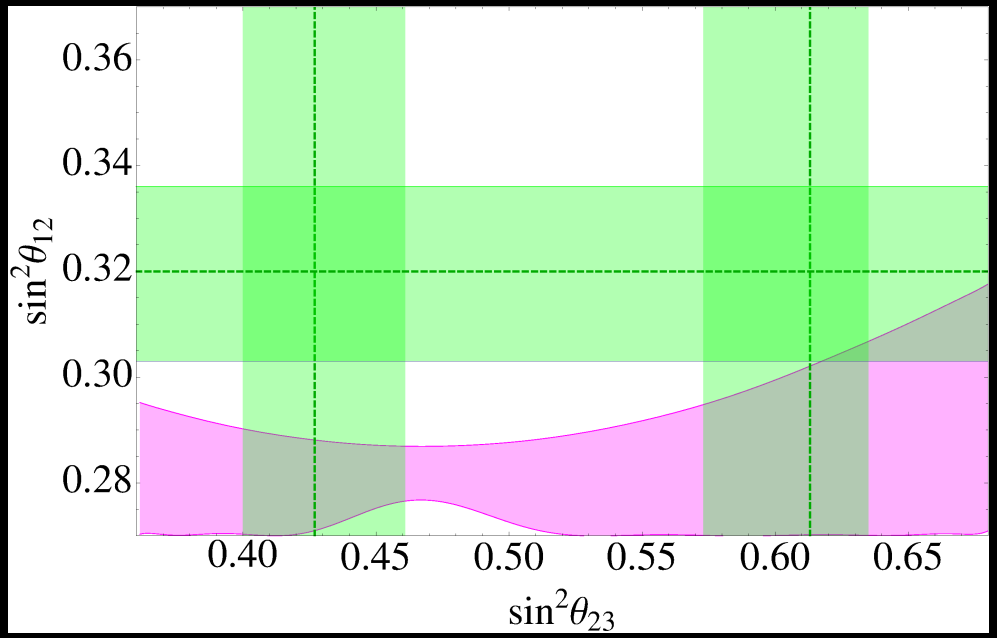


King et al: arXiv:1301.7065



Boucenna, et al 10.1103/PhysRevD.86.073008





Bazzocchi, F. et al
JHEP 1301 (2013) 033

Dorame, et al :
10.1103/PhysRevD.86.056001

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,§]

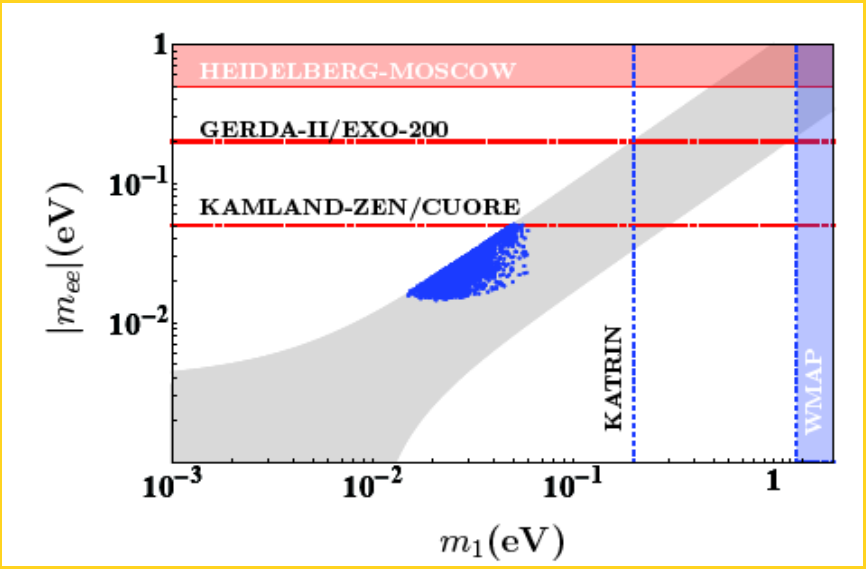
$$\frac{m_\tau}{\sqrt{m_e m_\mu}} \approx \frac{m_b}{\sqrt{m_d m_s}}$$

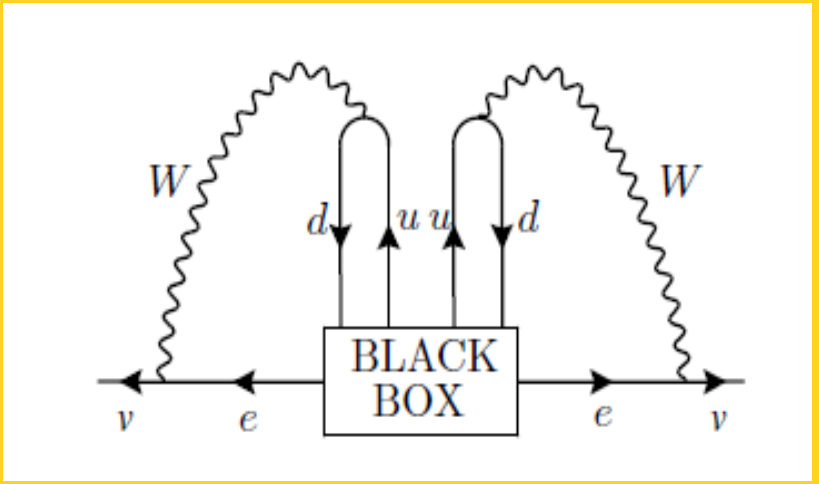
King et al: arXiv:1301.7065

Vub Vcb problem

http://arxiv.org/abs/arXiv:1303.4394

King et al arXiv:1301.7065



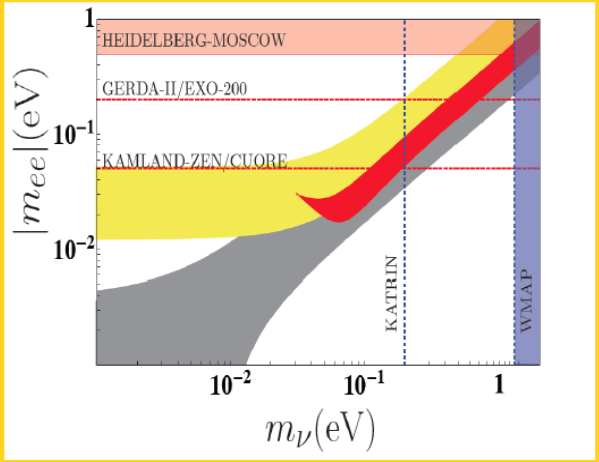


Schechter, Valle PRD25 (1982) 2951
Duerr, Lindner, Merle JHEP 1106 (2011) 091

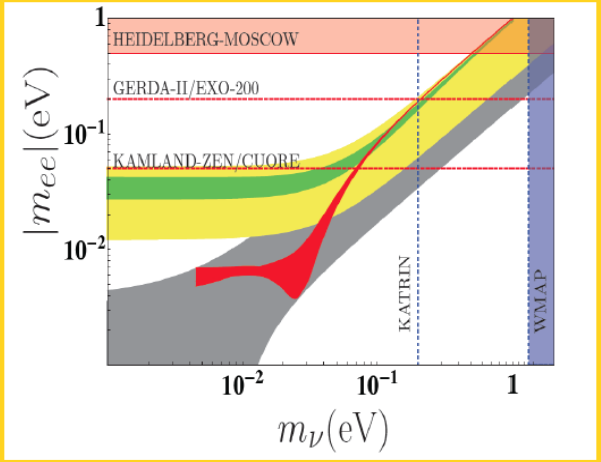
Flavor Sensitivity DBD lower bounds

Boucenna, et al
PhysRevD.86.073008

Dorame et al NPB861 (2012) 259-270

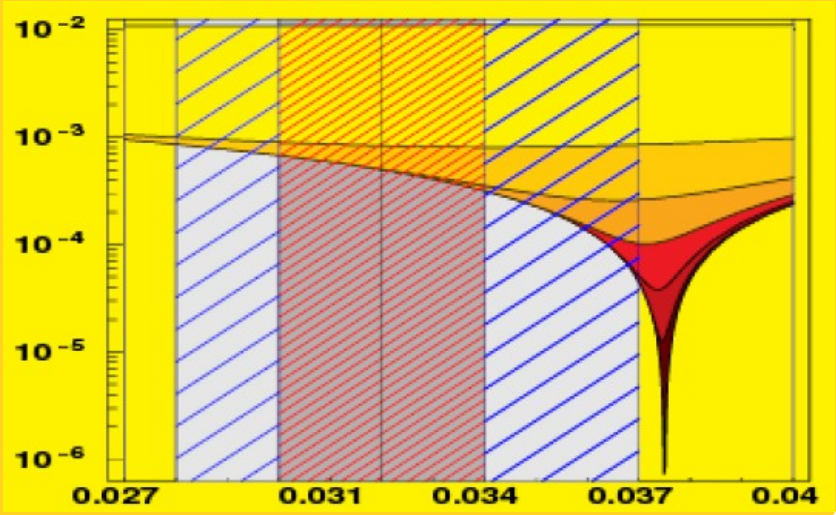


Dorame, et al :
PhysRevD.86.056001



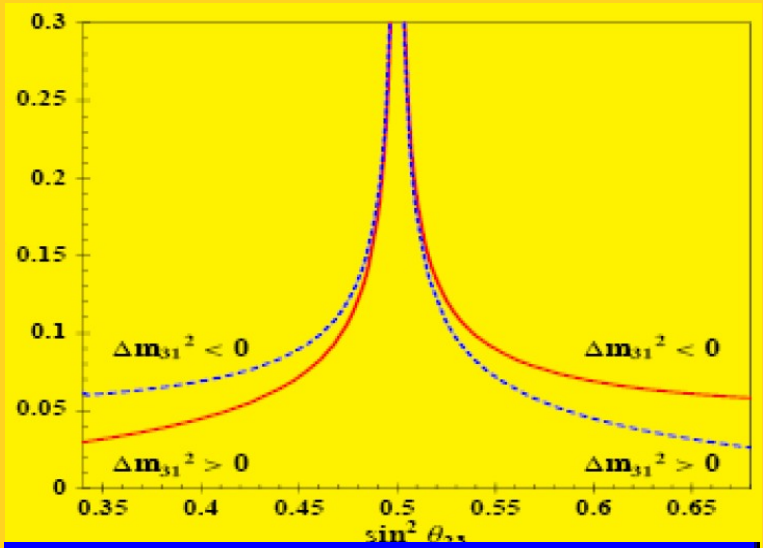
DBD & FLAVOR SYMMETRY

PRD78:093007 (2008)



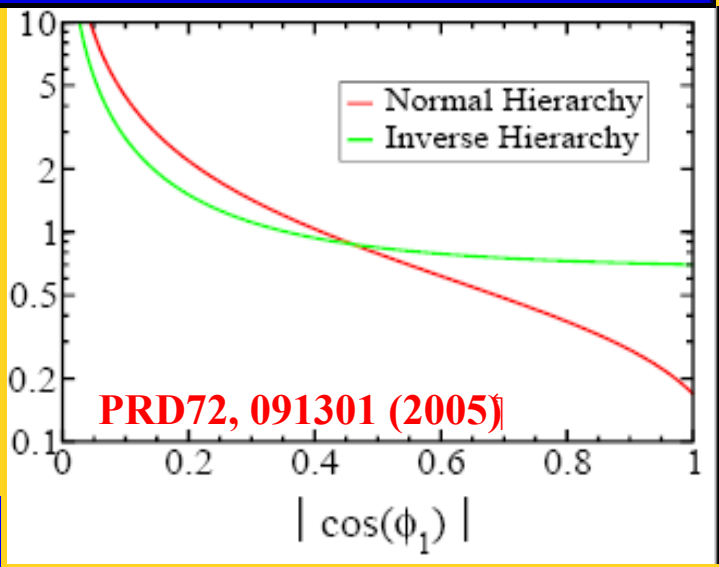
correlates with $\alpha = \frac{\Delta m^2_{\rm SOL}}{\Delta m^2_{\rm ATM}}$

PRL 99 (2007) 151802, PRD82 (2010) 073008



correlates with ATM angle

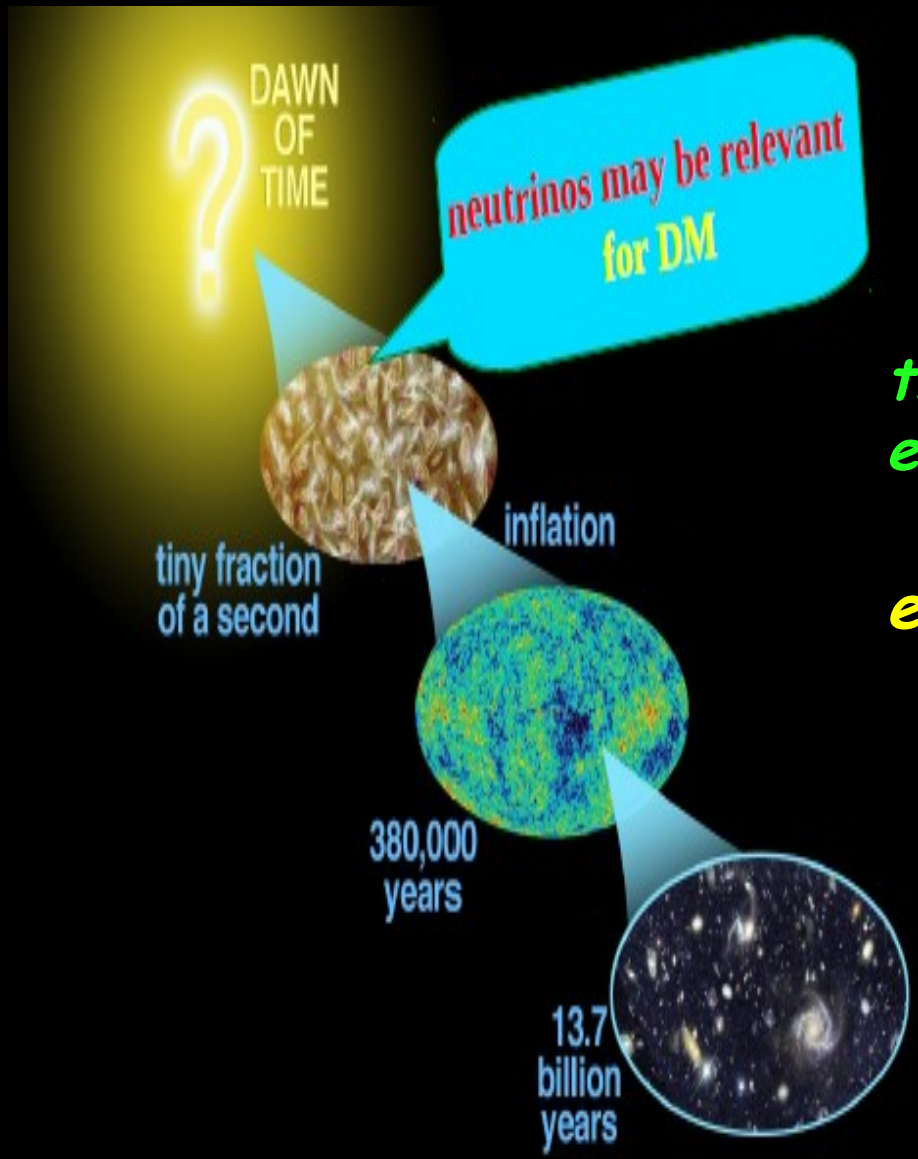
A4



correlates with Majorana phase

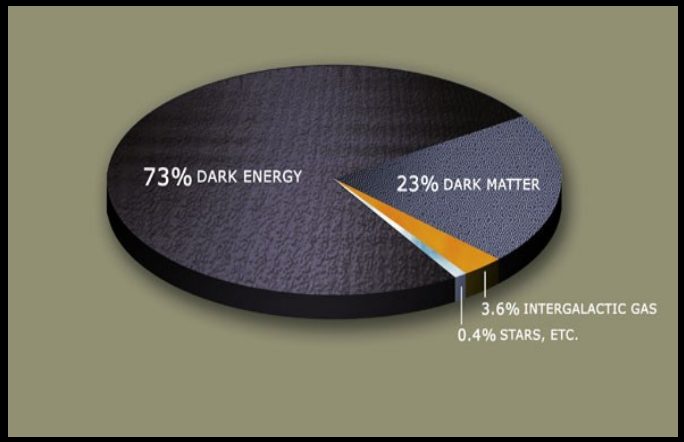
NEUTRINO DARK MATTER CONNECTION

though hardly important now, neutrino crucial in early Universe



they may probe the universe at earlier stages than photons

e.g. may seed Dark matter

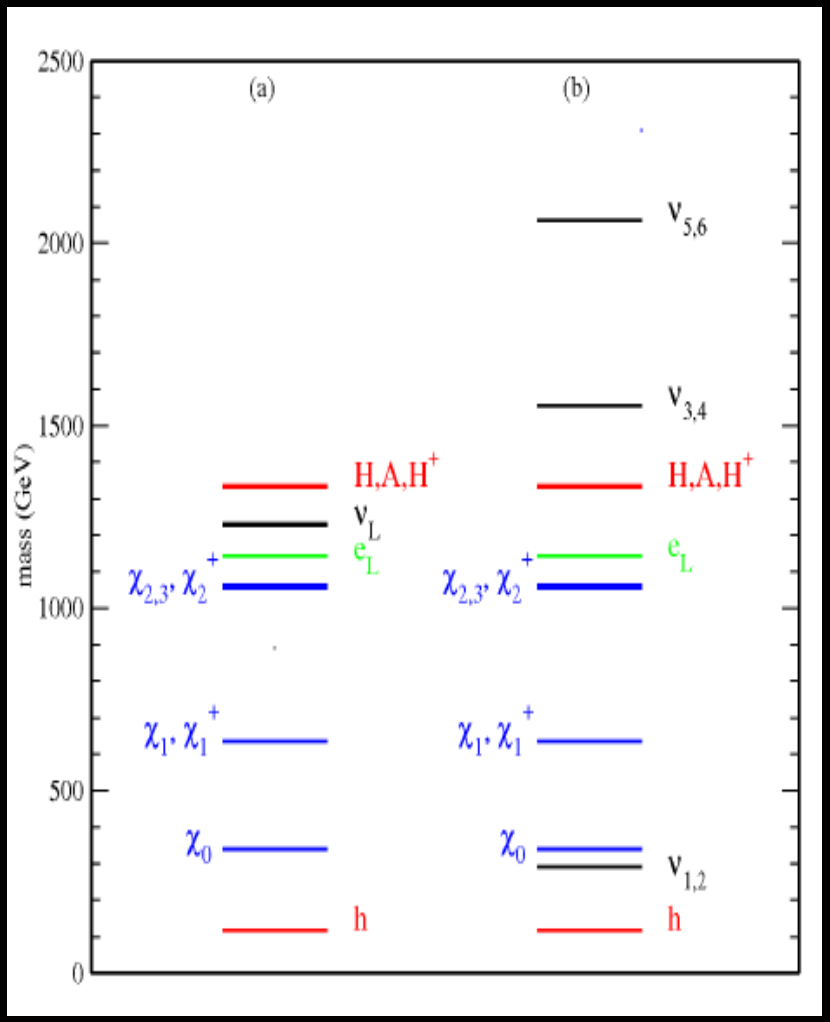


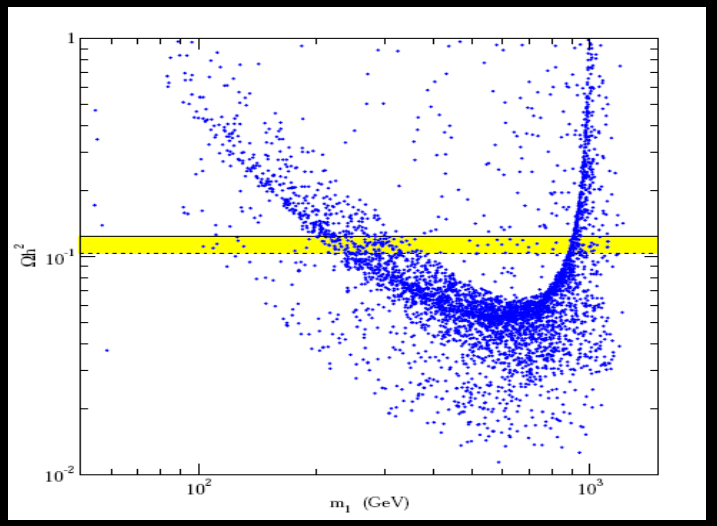
SNEUTRINO-like WIMP DM

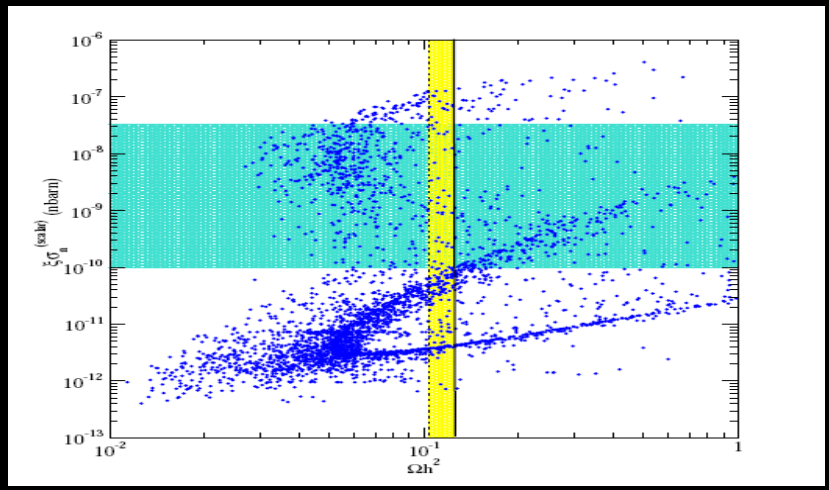
Arina et al PRL101 (2008) 161802

Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701

Inverse seesaw susy spectrum







DM STABILITY: ACCIDENT

Lavoura, Morisi, JV JHEP 1302 (2013) 118

From FLAVOUR SYMMETRY

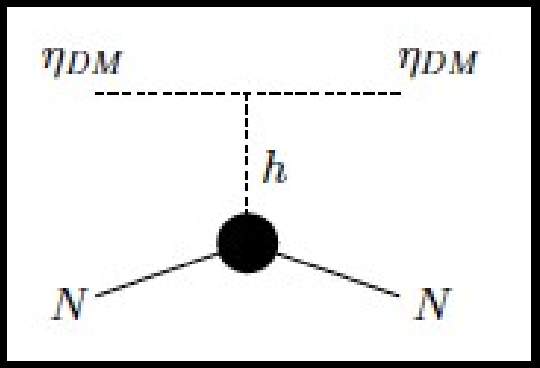
A4

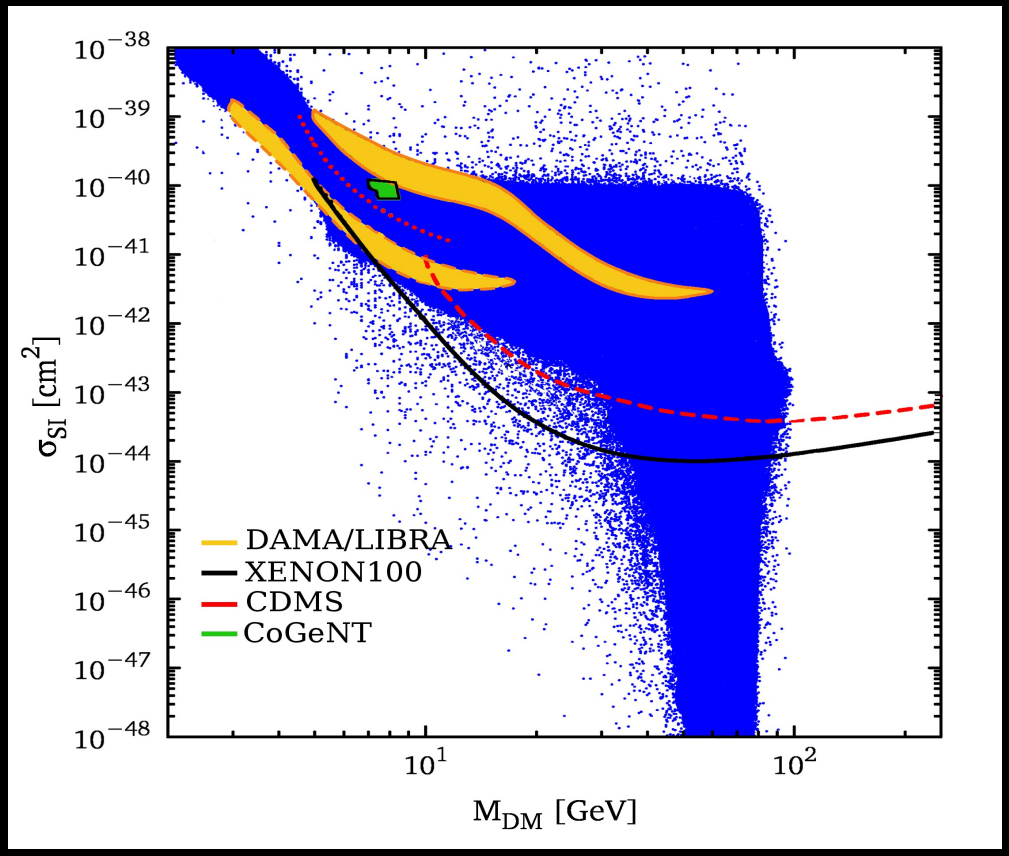
Hirsch, Morisi, Peinado, Valle
PRD82 116003 (2010)

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

Z2 PARITY

HIGGS PORTAL DETECTION

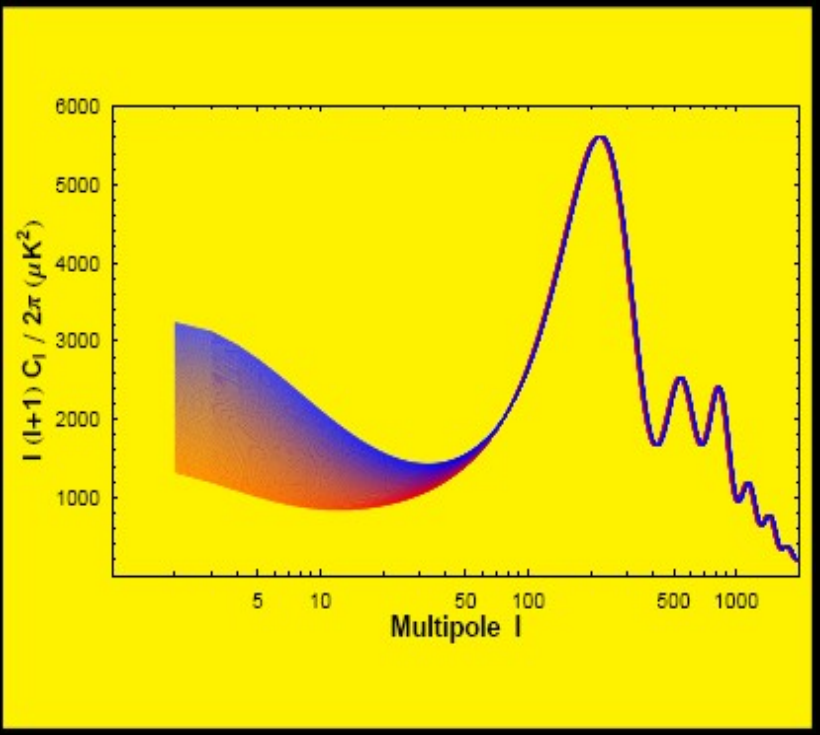


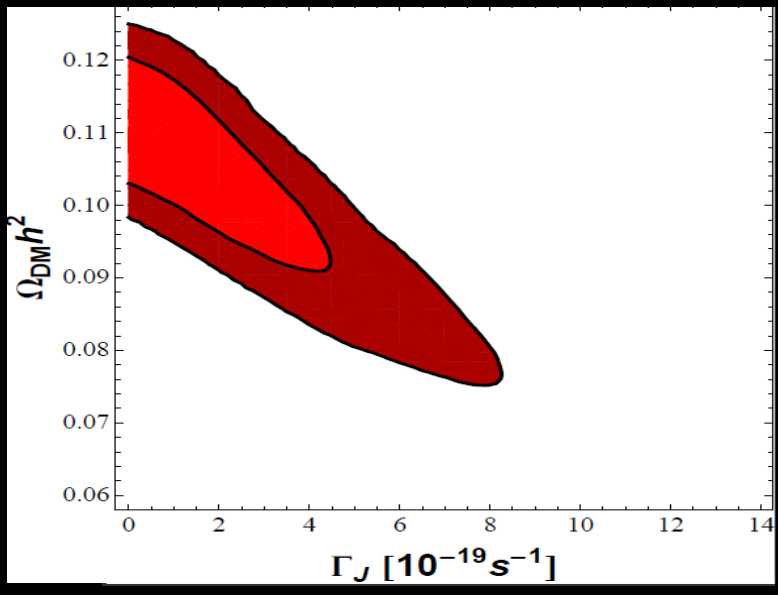


Majoron decaying DM Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

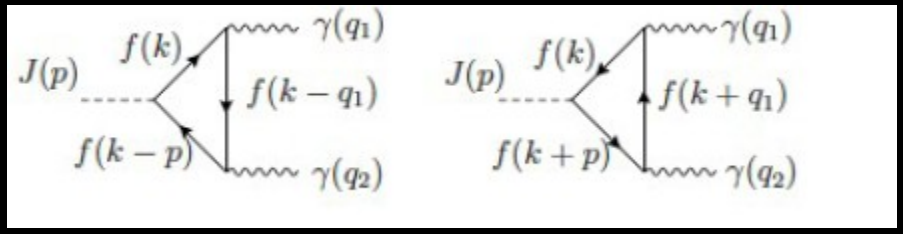
Lattanzi & Valle, PRL99 (2007) 121301

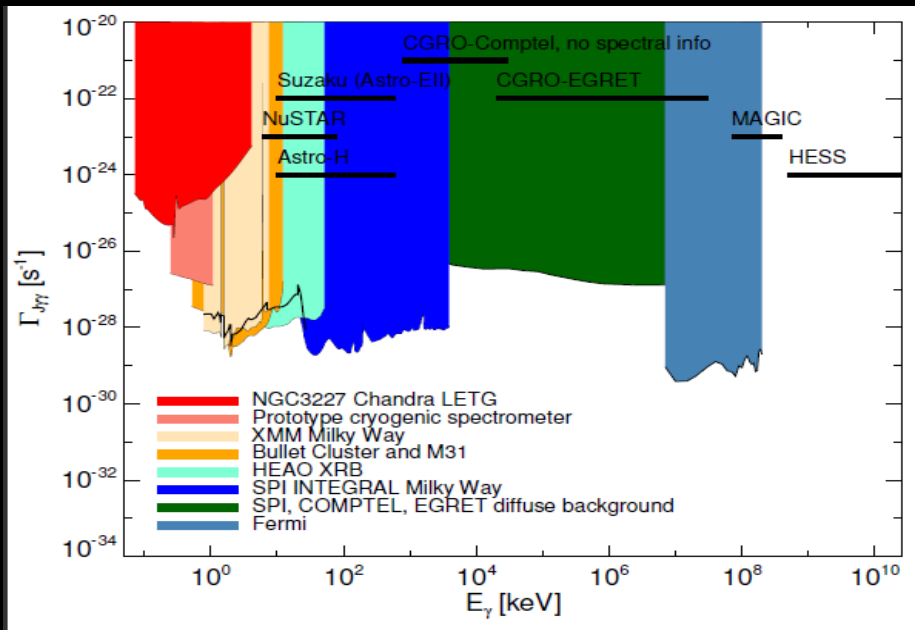




Esteves et al, PRD 82, 073008 (2010)

Bazzocchi & al JCAP 0808 (2008) 013





Gravitino as decaying dark matter **BRPV**

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

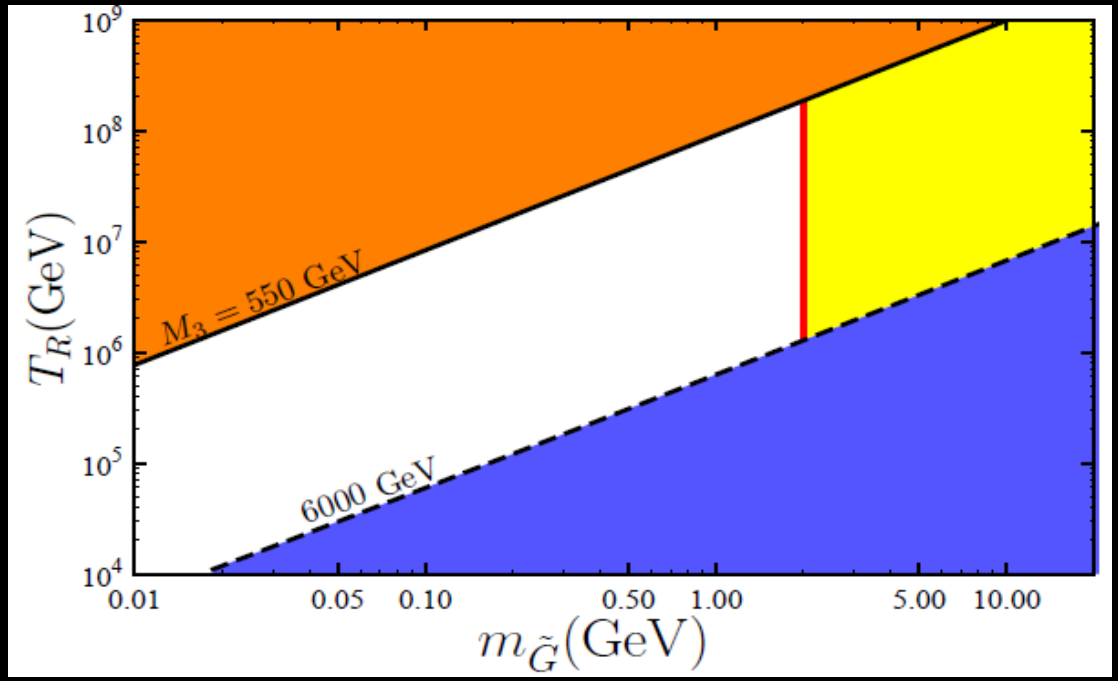
Restrepo et al
PRD85 (2012) 023523

relic abundance

+ Susy searches

excluded by gamma line searches @

Egret & Fermi-LAT



LHC TEST

OSCILLATIONS ROBUST , NEED SPECTRUM, CP & NSI

ORIGIN OF NEUTRINO MASS : WHICH MESSENGER?

MIXING PATTERN: ANARCHY or SYMMETRY?

DARK MATTER MAY RELATE TO NEUTRINOS

DARK MATTER STABILITY FROM FLAVOR SYMMETRY

MAJORON & GRAVITINO as DECAYING DARK MATTER

NEUTRINO PROPERTIES MAY BE TESTABLE AT LHC

DISPLACED VERTEX searches probe neutrino mass scale

LSP DECAY PATTERN probes neutrino mixing BRPV

THANKS !