Neutrino physics: current status and outlook

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ASTROPARTICLES
Astroparticles and High Energy Physics Group

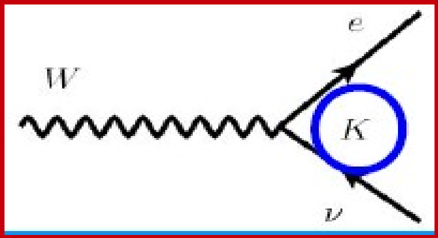
http://astroparticles.ific.uv.es/

LEPTON MIXING MATRIX

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

Schechter & JV PRD22 (1980) 2227 & PDG

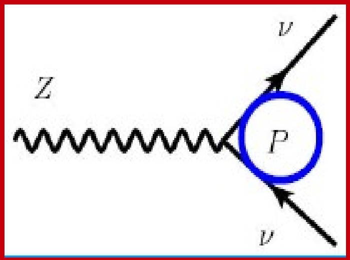
Rodejohann, JV Phys.Rev. D84 (2011) 073011



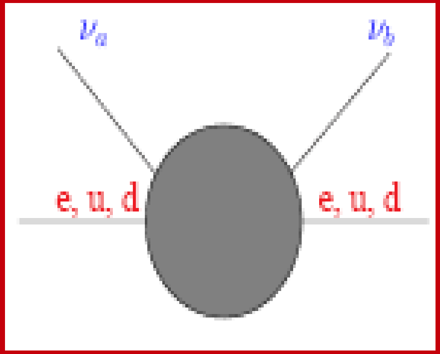
$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}}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

- 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



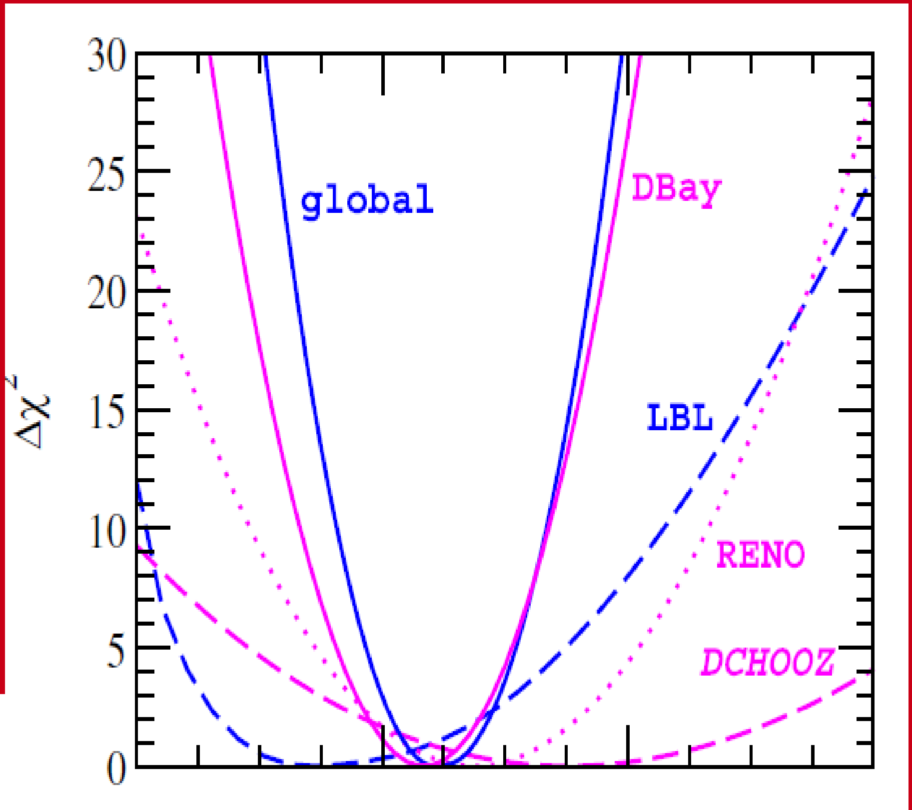
⇒



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

adopted in oscillation analyses

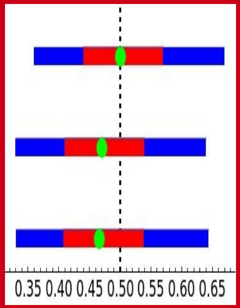
oscillation parameters

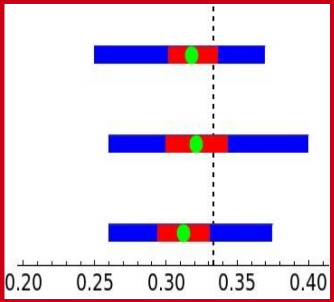


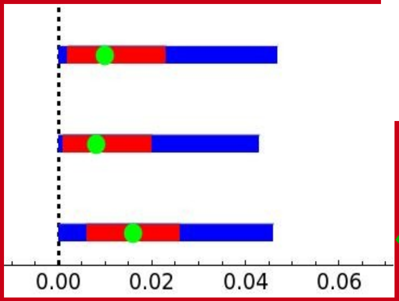
$\sin^2\theta_{13}$

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

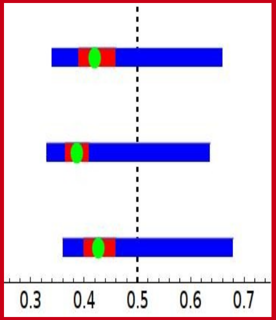
2011

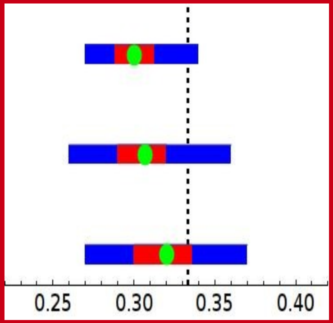


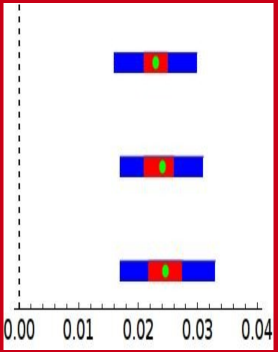




2012







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" THETA13

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

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

THETA23

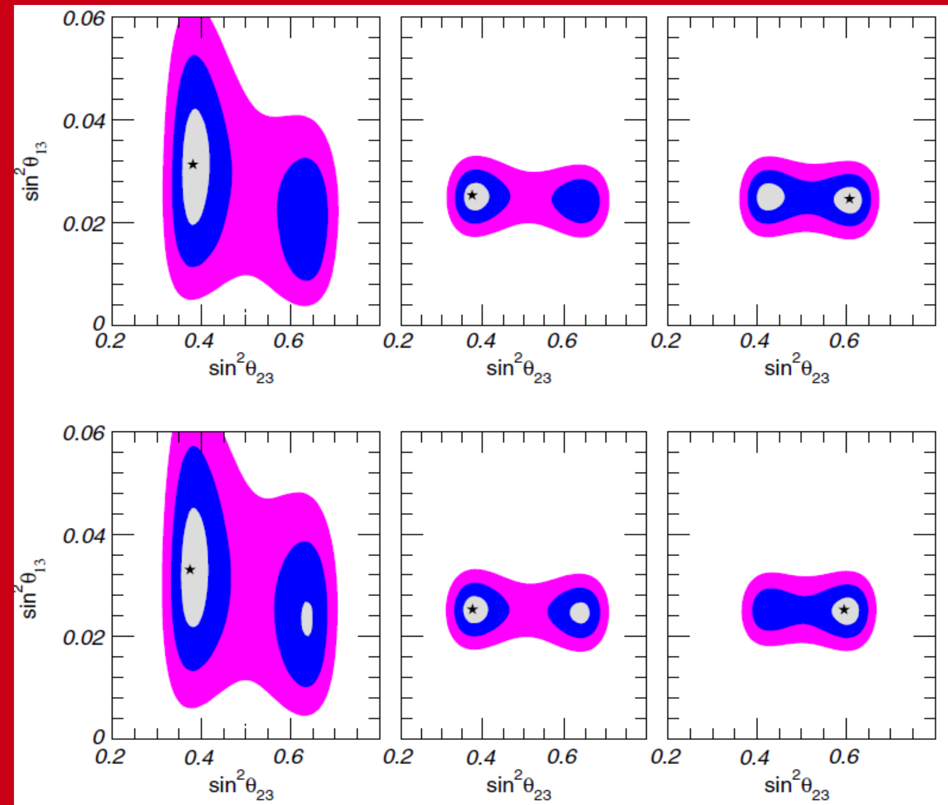
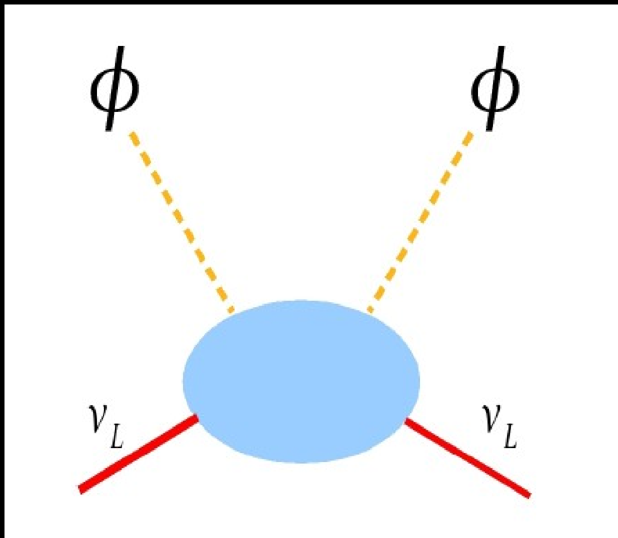


FIG. 3 (color online). Upper panels: contour regions with $\Delta\chi^2 = 1, 4, 9$ in the $\sin^2\theta_{23} - \sin^2\theta_{13}$ plane from the analysis of long-baseline (MINOS and T2K) + solar + KamLAND data (left-hand panel), long-baseline + solar + KamLAND + new Double Chooz, Daya Bay and RENO reactor data (middle panel) and the global combination (right-hand panel) for normal hierarchy. Lower panels, same but for (inverted) neutrino mass hierarchy.

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

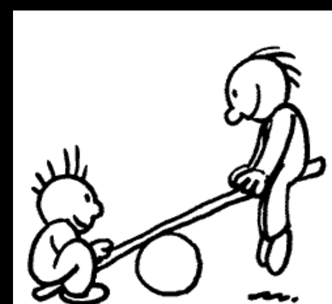
TYPE II

Schechter-Valle 80/82

SCALE

MECHANISM

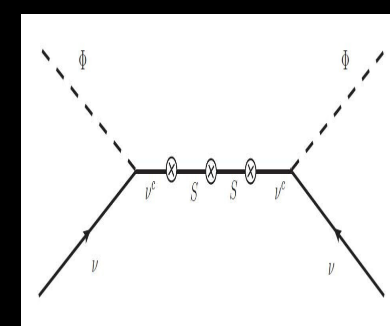
FLAVOR STRUCTURE



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

LOW-SCALE SEESAW

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



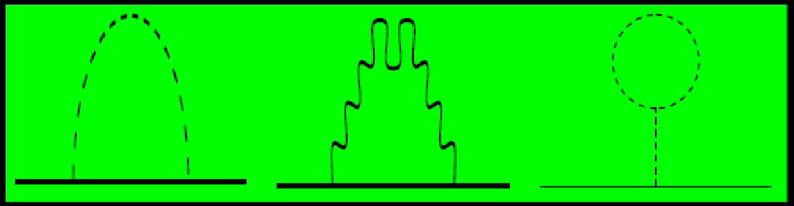
SUSY ORIGIN OF NU-MASS

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

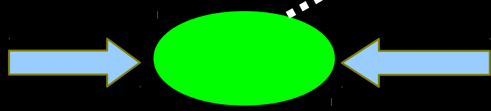
Diaz et al PRD68 (2003) 013009, PRD62 (2000) 113008
PRD65 (2002) 119901; PRD61 (2000) 071703
Bazzocchi et al arXiv:1202.1529

NEUTRALINO DECAYS: PROBING NUs @ LHC

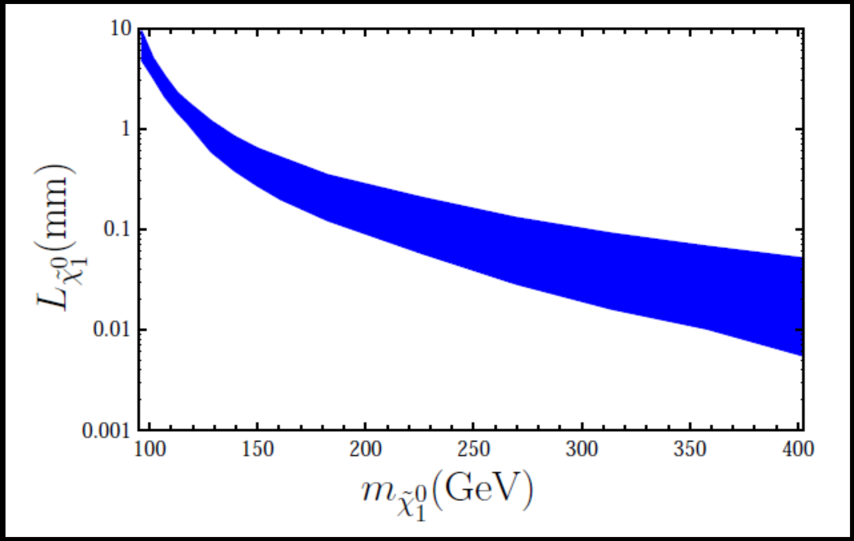
De Campos et al
Phys.Rev. D86 (2012) 075001
PRD82 (2010) 075002 &
JHEP 0805:048, 2008

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

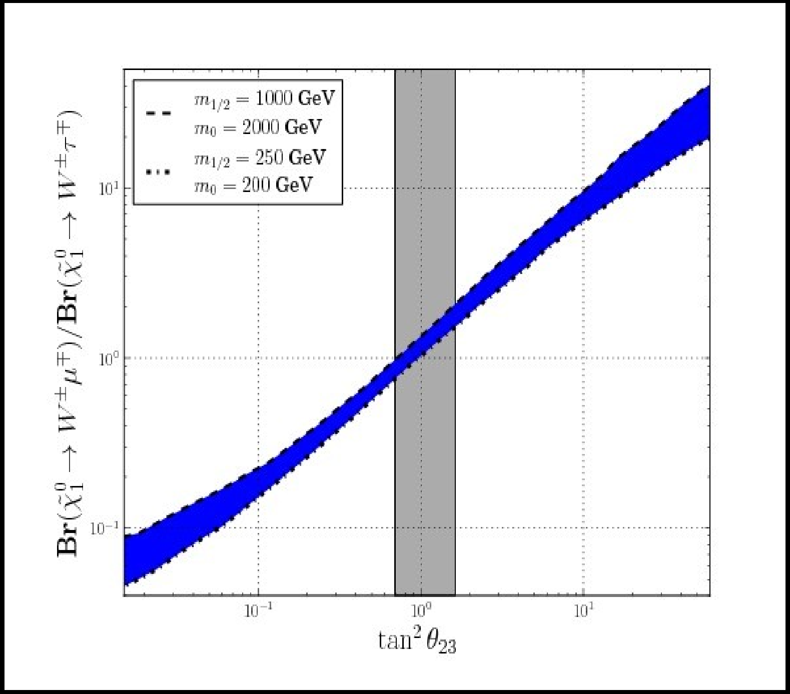
$$\tilde{\chi}_1^0 \to Z^0 \nu_i$$



Lightest neutralino decay length



Lightest neutralino decay correlates with atm angle



The flavor problem

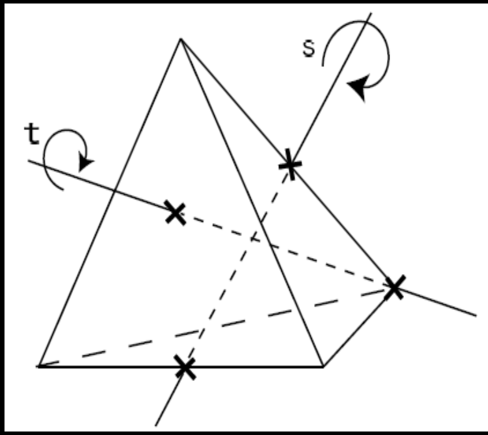
$$\begin{pmatrix}\nu_e\\ e\end{pmatrix}_L \quad \begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}_L \quad \begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}_L$$

$$e_R \quad \mu_R \quad \tau_R$$

$$\begin{pmatrix}u\\ d\end{pmatrix}_L \quad \begin{pmatrix}c\\ s\end{pmatrix}_L \quad \begin{pmatrix}t\\ b\end{pmatrix}_L$$

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$



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

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

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

G_{flavor}

Deviation of TBM

Ishimori,et al Prog Theor Phys Suppl 183 (2010) 1

Nilles, Morisi, JV Z. fur Phys, 2012

Holthausen et al 1212.2411

FLASY2011, FLASY12, …

Different ansatz:

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

Albright,Dueck,Rodejohann 1004.2798

Bi-Trimaximal

King, Luhn, Stuart 1207.5741

Bi-large

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

Anarchy

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

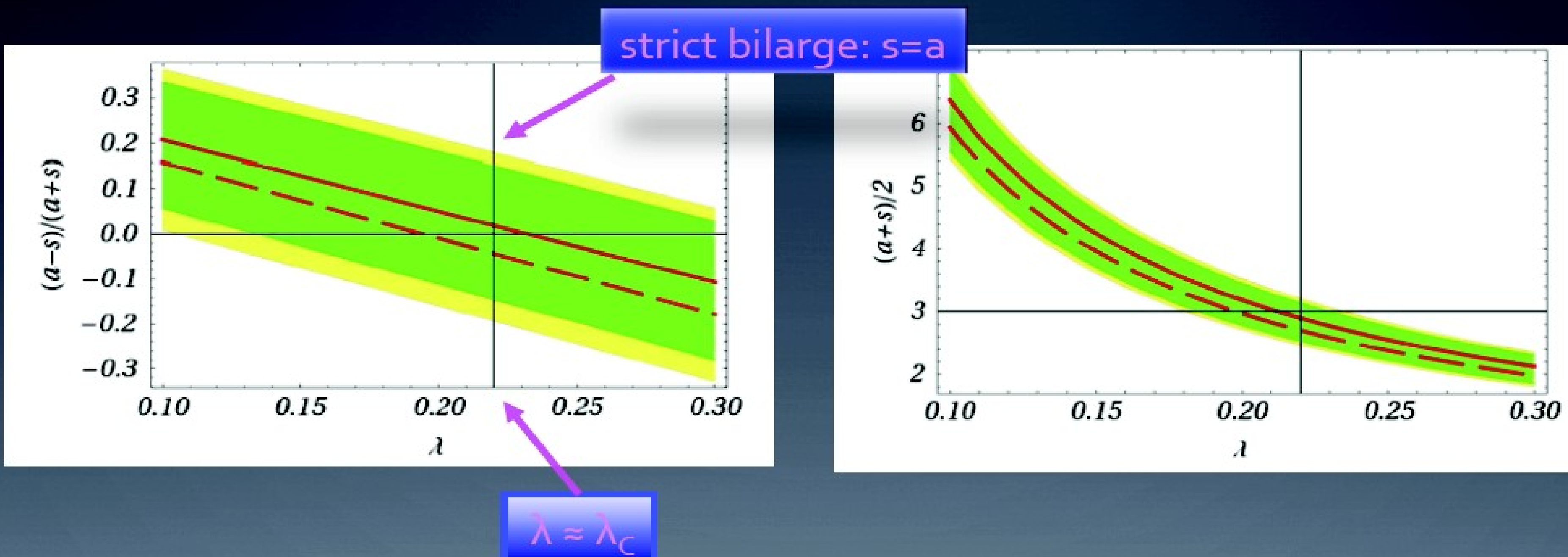
Bi-large instead of TBM *(after MINOS, Daya-Bay, etc)*

Reactor angle seeds solar & Atm

Boucenna et al PRD86 **1206.2555**

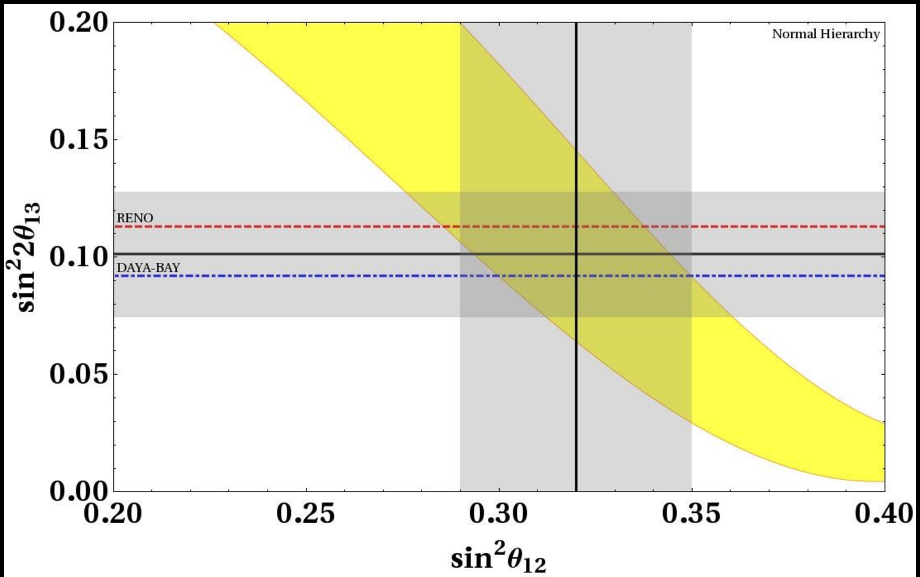
$\sin^2\theta_{13} = \lambda$
$\sin^2\theta_{12} = s\lambda$
$\sin^2\theta_{23} = a\lambda$

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



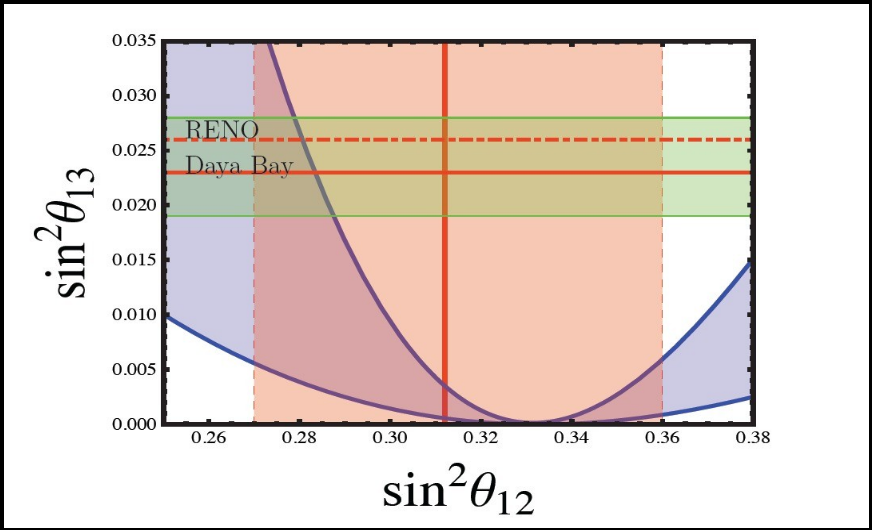
Models: Ding, Morisi, JV 1211.6506 … Roy & Singh, ...

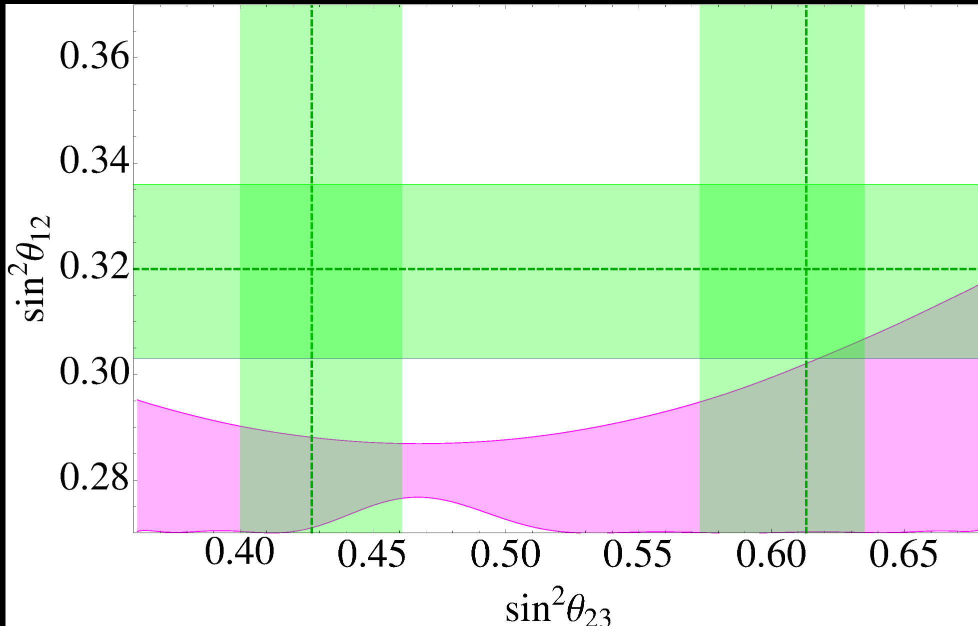
OSCILLATION PARAMETER CORRELATIONS **LARGE THETA13**



Dorame, et al :
10.1103/PhysRevD.86.056001

Boucenna, et al
10.1103/PhysRevD.86.073008





Bazzocchi, S. et al
JHEP 2012

Dorame, et al :
10.1103/PhysRevD.86.056001

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

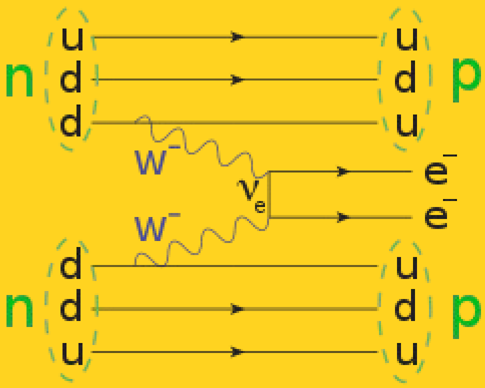
Relating quarks and leptons without grand unification

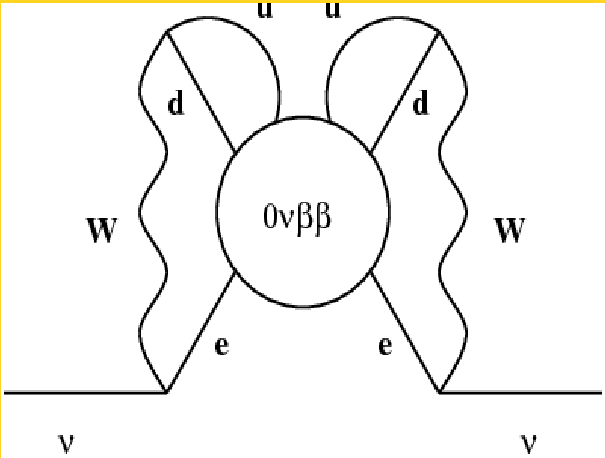
S. Morisi,[1,*] E. Peinado,[1,†] Yusuke Shimizu,[2,‡] and J. W. F. Valle[1,§]

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

TESTING NEUTRINO SPECTRA W/ NU-LESS DBD

NH VERSUS IH





Schechter, Valle PRD25 (1982) 2951

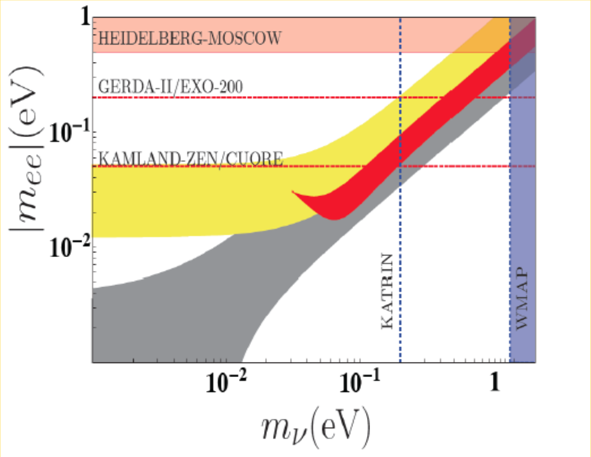
Duerr, Lindner, Merle JHEP 1106 (2011) 091

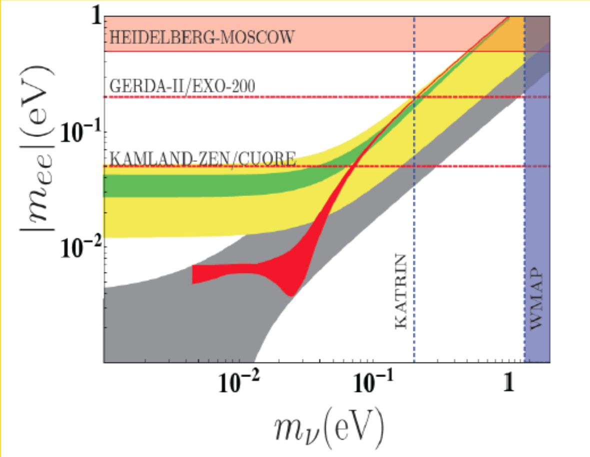
Flavor Sensitivity DBD lower bounds

Boucenna, et al 10.1103/PhysRevD.86.073008

Dorame et al NPB861 (2012) 259-270

Dorame, et al : 10.1103/PhysRevD.86.056001

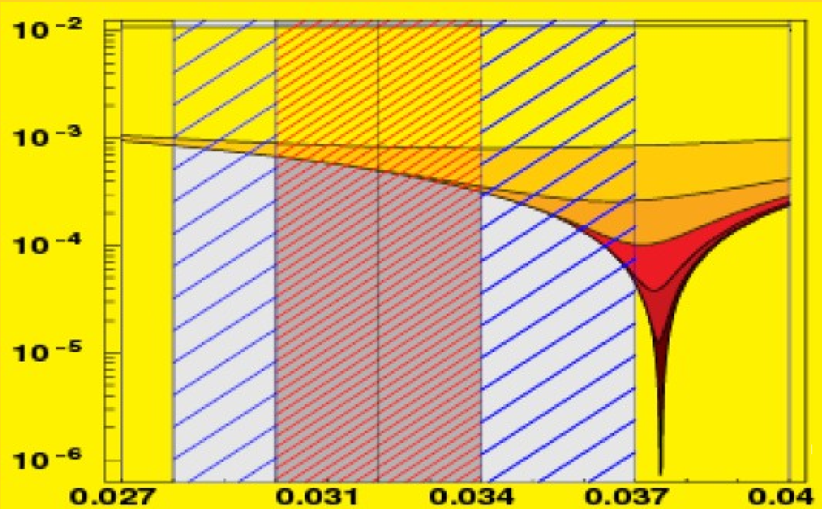




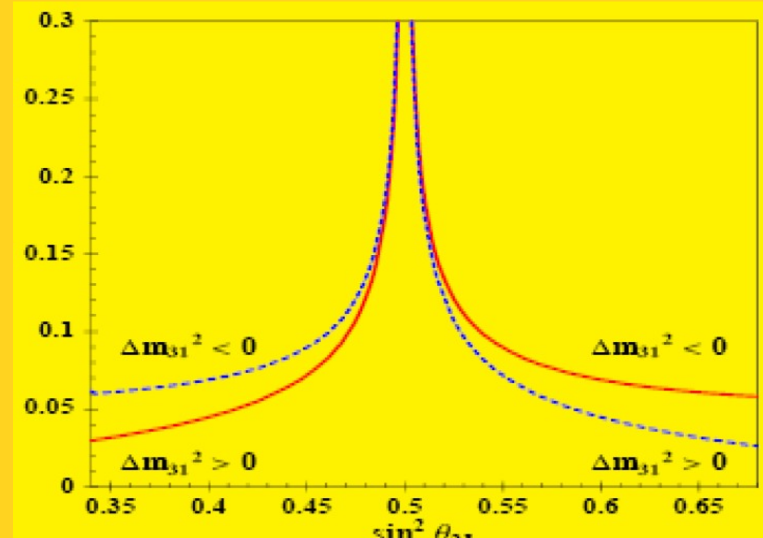
DBD & FLAVOR SYMMETRY

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

PRD78:093007 (2008)

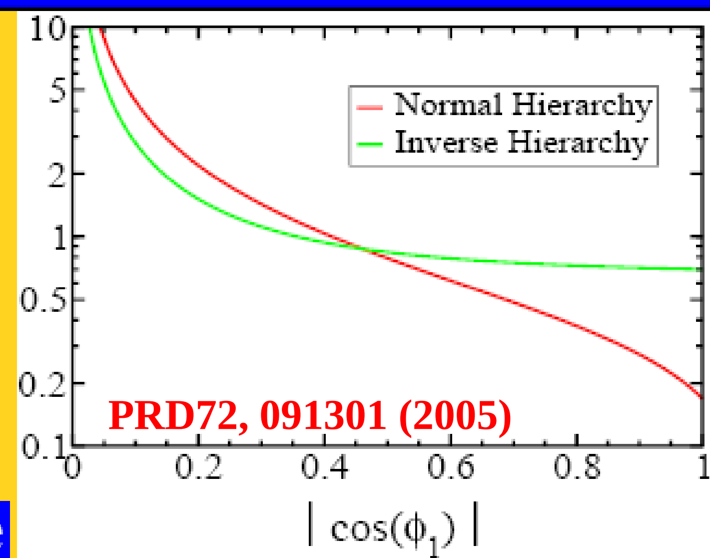


correlates with $\alpha = \frac{\Delta m^2_{SOL}}{\Delta m^2_{ATM}}$



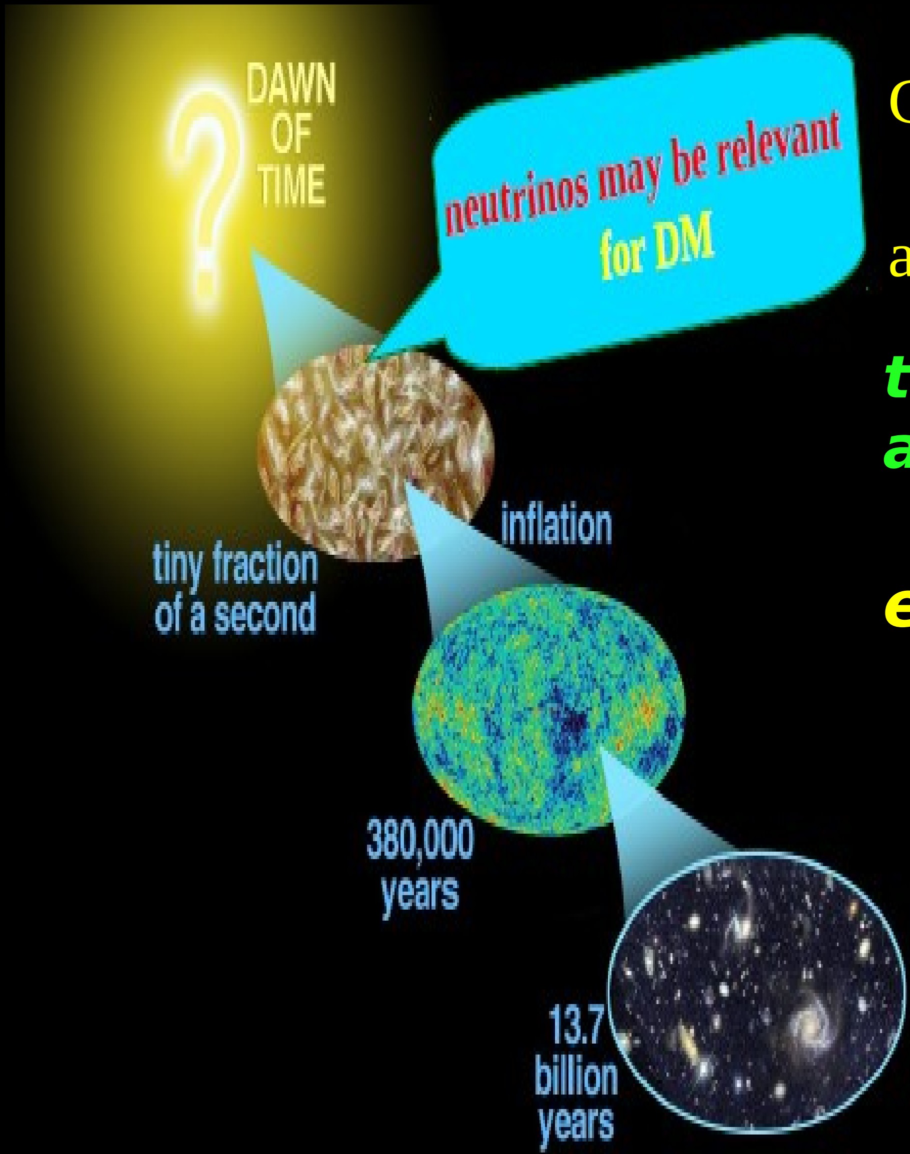
correlates with ATM angle

A4



correlates with Majorana phase

NEUTRINO DARK MATTER CONNECTION



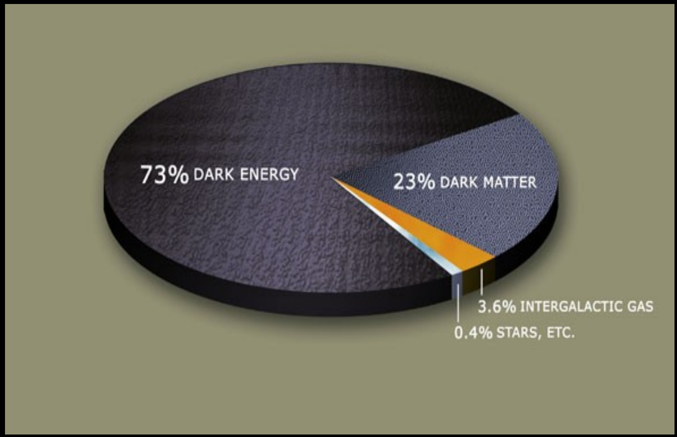
though hardly important now,neutrinos are crucial in the early Universe

Govern the synthesis of light elements,

and affect the large scale structure ...

they may probe the universe at earlier stages than photons

e.g. may seed Dark matter

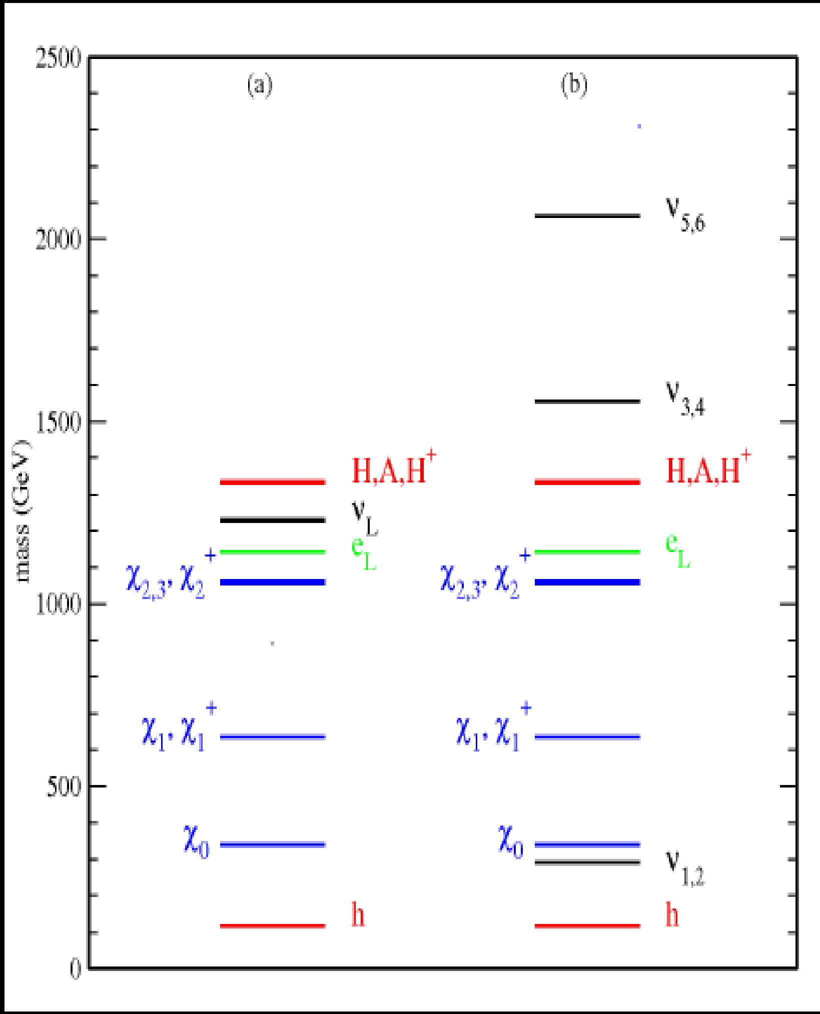


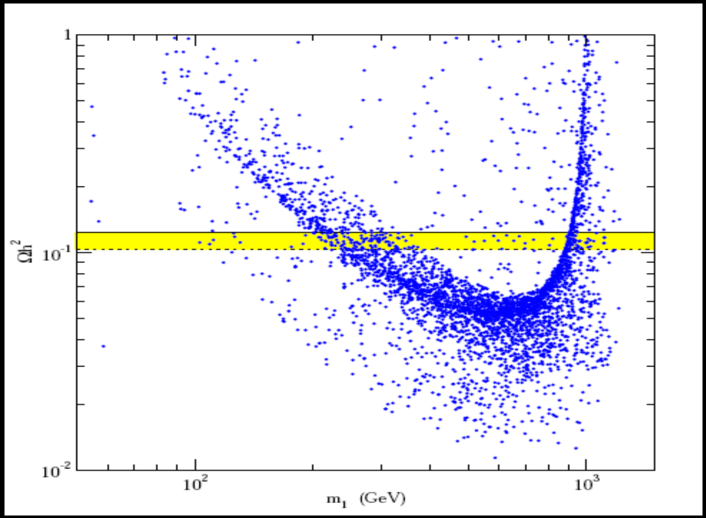
SNEUTRINO-like WIMP DM

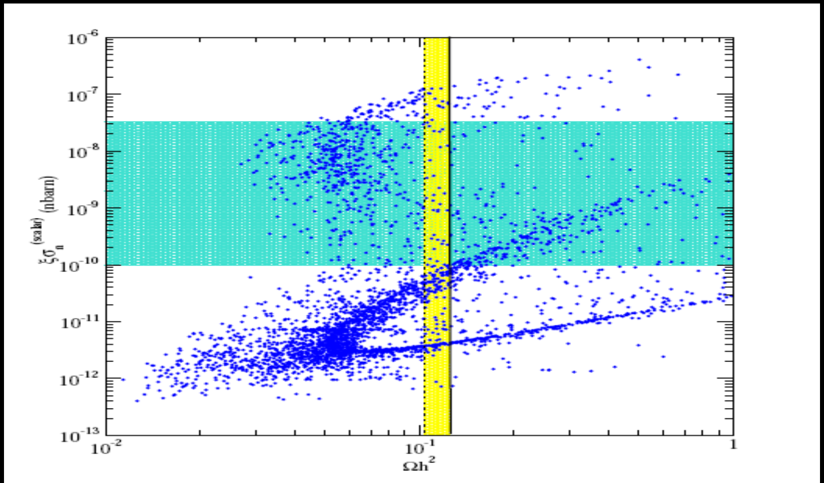
Arina et al PRL101 (2008) 161802

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

Inverse seesaw susy spectrum







DM STABILITY: ACCIDENT

Lavoura, Morisi, Valle. arXiv:1205.3442

From FLAVOUR SYMMETRY NEUTRINO MIXING

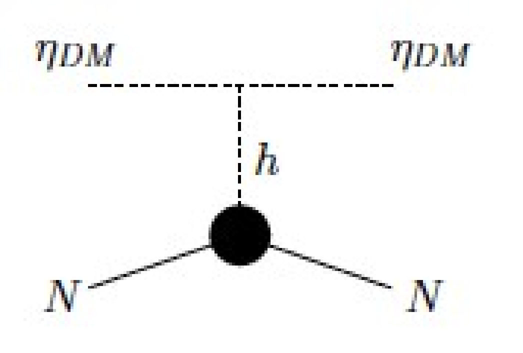
A4

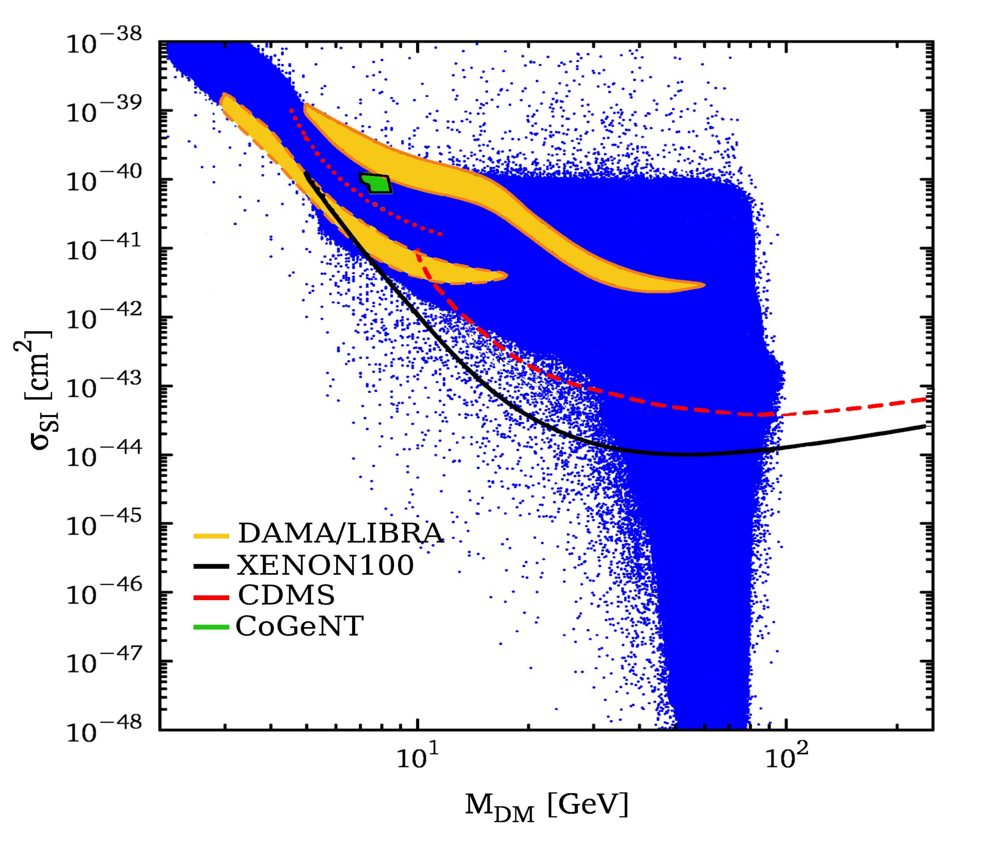
Hirsch, Morisi, Peinado, Valle
PRD82 116003 (2010)

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

Z2 PARITY

HIGGS PORTAL
DETECTION



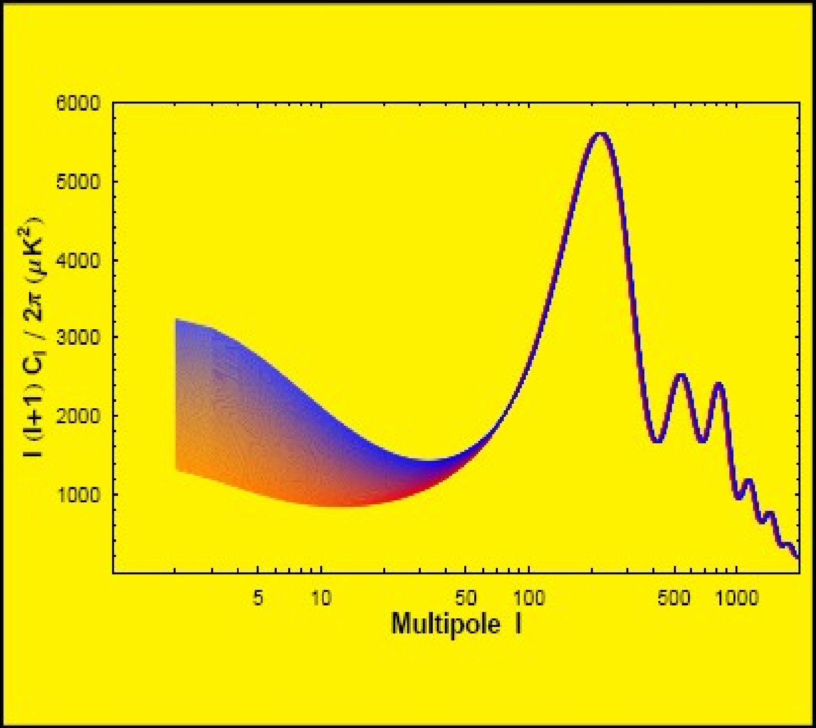


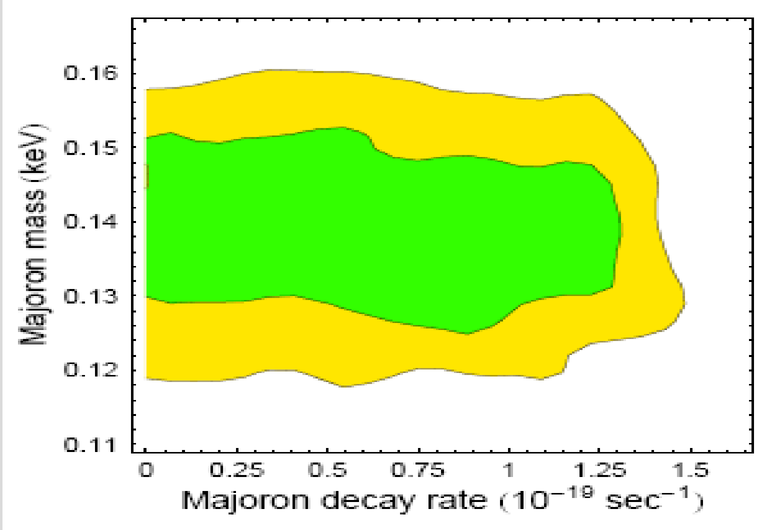
Majoron decaying non-WIMP DM

Berezinsky, Valle PLB318 (1993) 3

Consistency with CMB

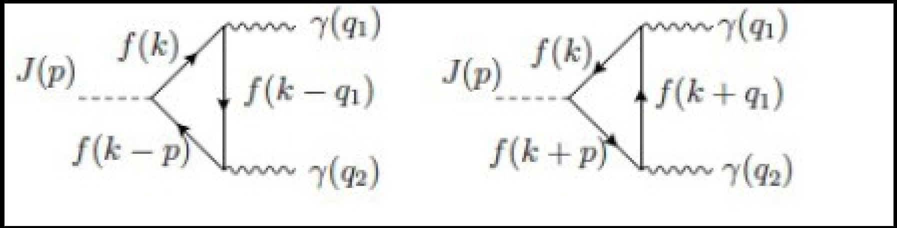
Lattanzi & Valle, PRL99 (2007) 121301

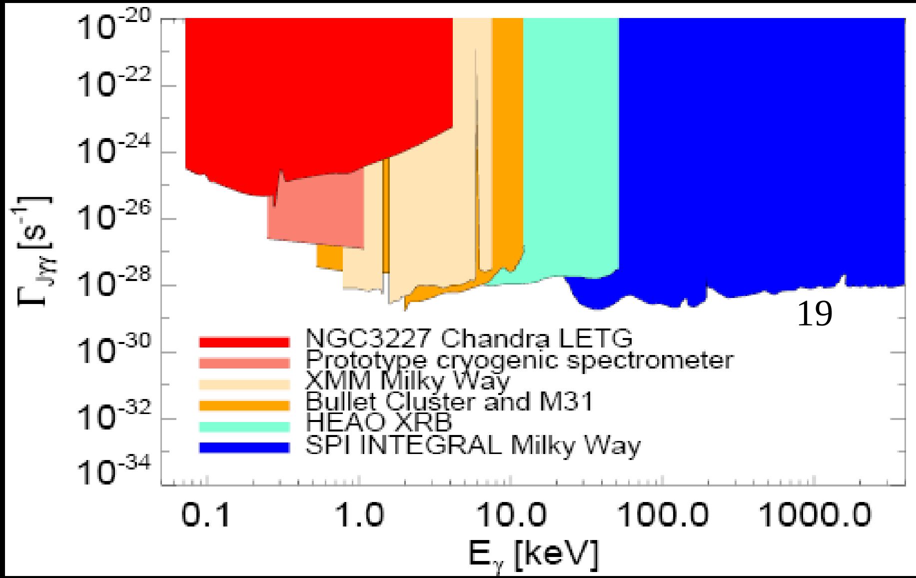




Esteves et al, PRD 82, 073008 (2010)

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

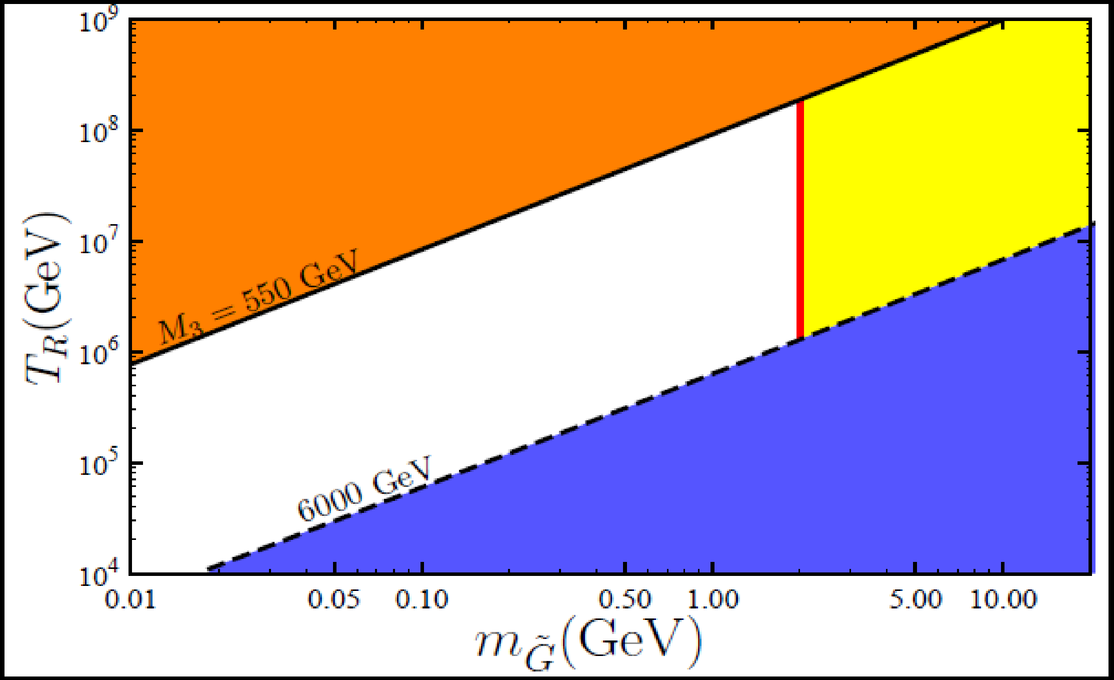
Restrepo et al
PRD85 (2012) 023523

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

Thank you