neutrino masses and mixing: evidences and implications

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http://astroparticles.es/

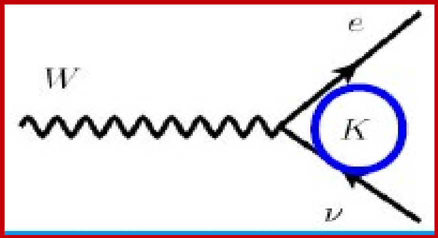
PASCOS2012, Merida, June

LEPTON MIXING MATRIX

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

Schechter & JV PRD22 (1980) 2227 & PDG

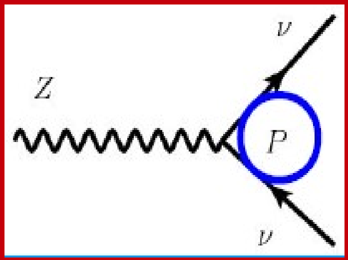
Rodejohann, JV Phys.Rev. D84 (2011) 073011

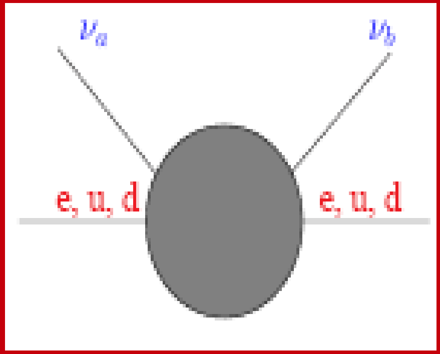


$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}}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

- 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 NC
NSI & new LFV effects



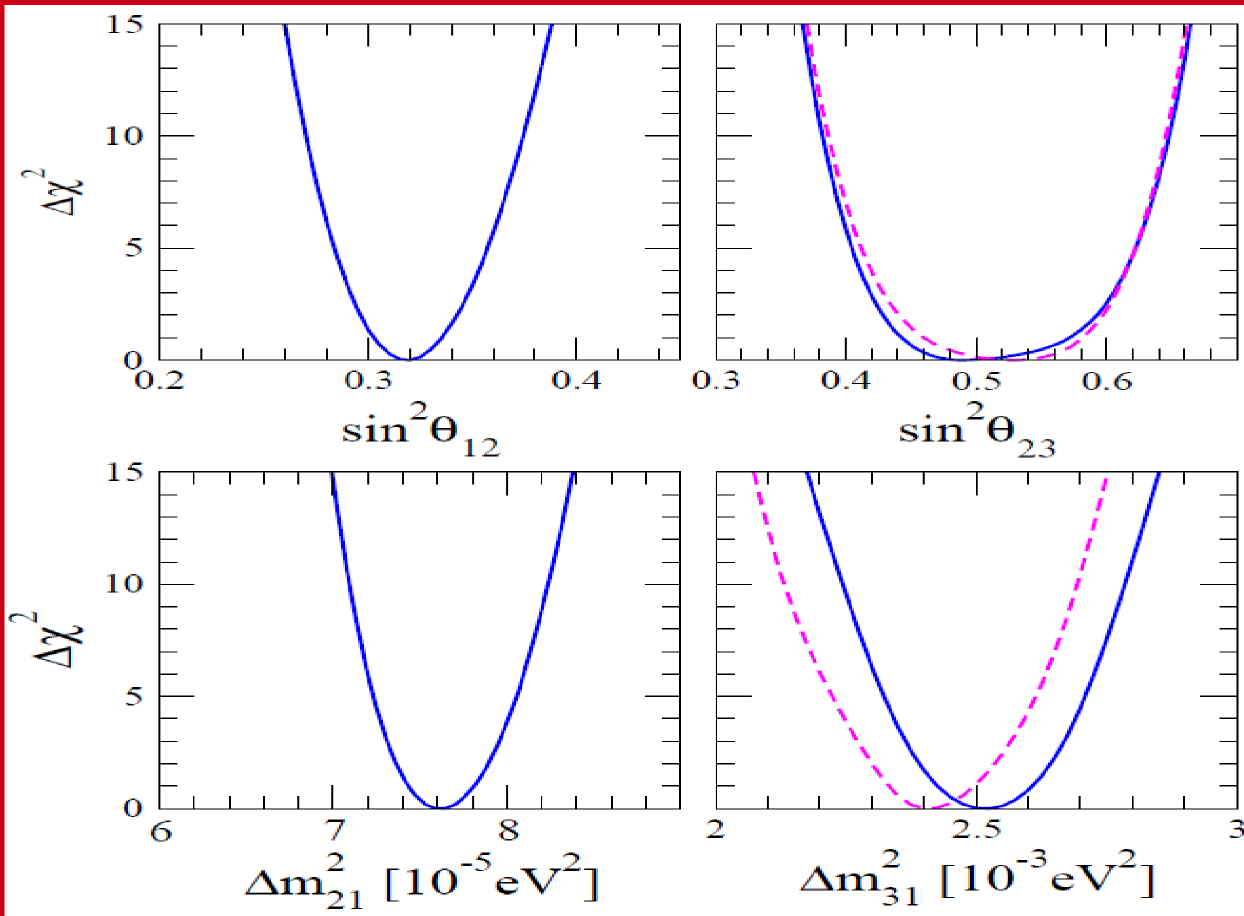


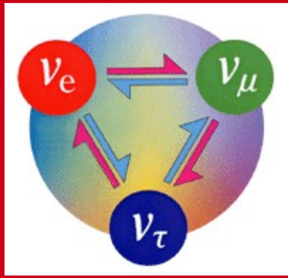
$$\begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

adopted in oscillation analyses

OSCILLATION PARAMETERS 2012

Forero, Tortola, Valle **arXiv:1205.4018**





New J.Phys. 13 (2011) 109401
13 (2011) 063004

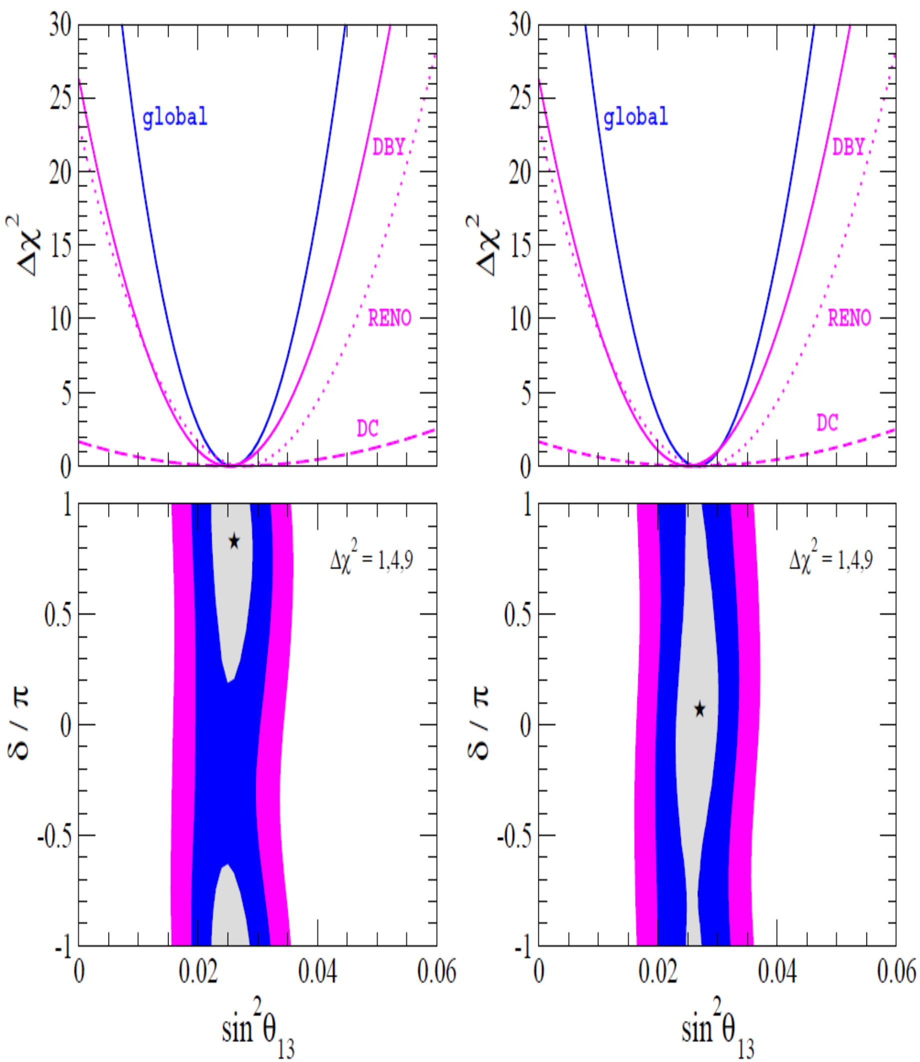
DoubleChooz, DayaBay, RENO

MINOS & T2K

ROBUST "LARGE" THETA13

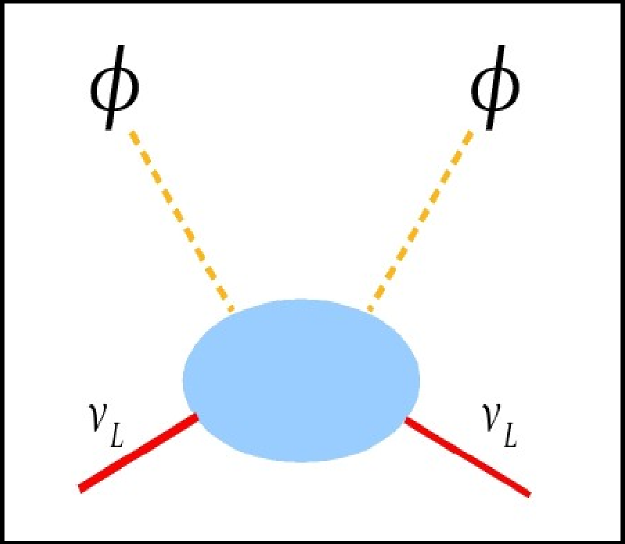
CPV, hierarchy @LBL **Gouvea**

Forero, Tortola, Valle **arXiv:1205.4018**



parameter	best fit $\pm 1\sigma$	2σ	3σ
$\Delta m^2_{21}\ [10^{-5}\mathrm{eV}^2]$	7.62 ± 0.19	7.27–8.01	7.12–8.20
$\Delta m^2_{31}\ [10^{-3}\mathrm{eV}^2]$	$2.53^{+0.08}_{-0.10}$ $-(2.40^{+0.10}_{-0.07})$	$2.34 - 2.69$ $-(2.25 - 2.59)$	$2.26 - 2.77$ $-(2.15 - 2.68)$
$\sin^2\theta_{12}$	$0.320^{+0.015}_{-0.017}$	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	$0.49^{+0.08}_{-0.05}$ $0.53^{+0.05}_{-0.07}$	0.41–0.62 0.42–0.62	0.39–0.64
$\sin^2\theta_{13}$	$0.026^{+0.003}_{-0.004}$ $0.027^{+0.003}_{-0.004}$	0.019–0.033 0.020–0.034	0.015–0.036 0.016–0.037
δ	$\left(0.83^{+0.54}_{-0.64}\right)\pi$ 0.07π [a]	$0 - 2\pi$	$0 - 2\pi$

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

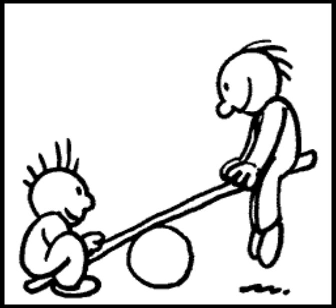
TYPE II

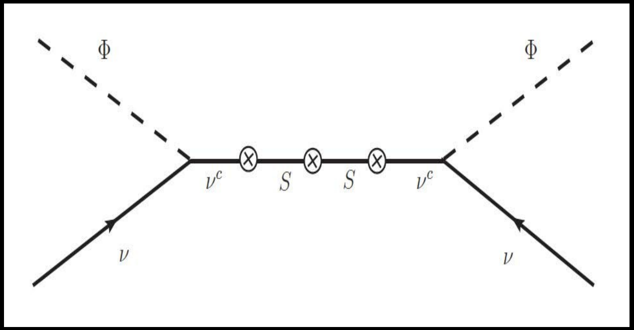
Schechter-Valle 80/82

SCALE

MECHANISM

FLAVOR STRUCTURE





LOW-SCALE SEESAW

Mohapatra-Valle 86

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

PRL **95,** 161801 (2005) PHYSICAL REVIEW LETTERS week ending 14 OCTOBER 2005

Low-scale seesaw in GUTS

Supersymmetric SO(10) Seesaw Mechanism with Low *B*-*L* Scale

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J. W. F. Valle‡

precision indirect Z' search, complementary to Drell-Yan@LHC

GARCÉS *et al.* PHYSICAL REVIEW D **85,** 073006 (2012)

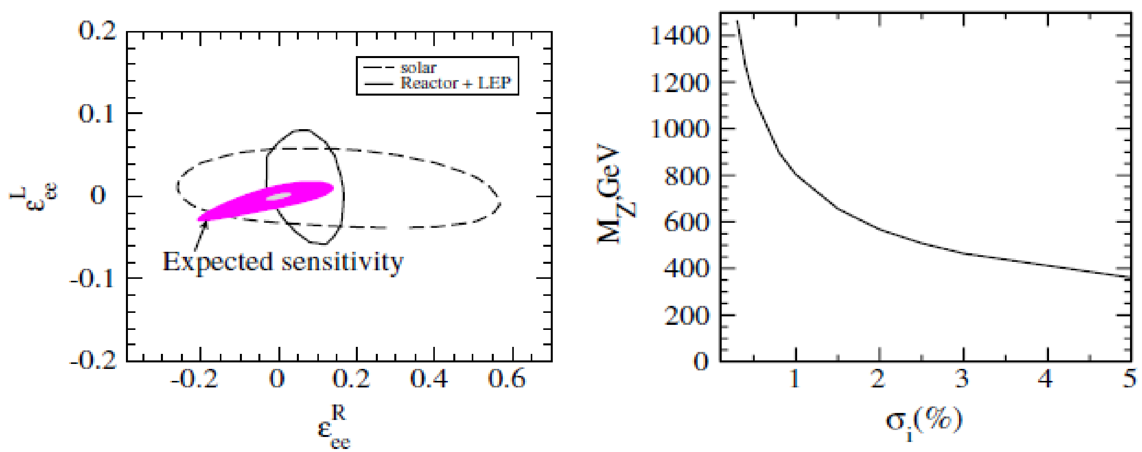


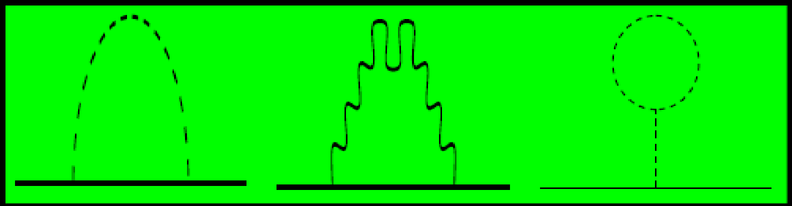
FIG. 3 (color online). Left panel: Expected LENA sensitivity at 90% CL to nonuniversal NSI using a ^{51}Cr neutrino source. The shaded areas correspond to a binned data sample divided in seven bins of 50 keV each and an error per bin of either 1% (grey inner region) or 5% (magenta outer region). For comparison, we show current limits to these parameters from an analysis coming from solar and KamLAND neutrino data [28] (dashed line) as well as from an analysis to the LEP and reactor data [29] (solid line). Right panel: Expected sensitivity at 90% CL to the mass of a new neutral gauge boson coupled to lepton number [18]. In both cases, we fix the weak mixing angle as $\sin^2\theta_W = 0.2313$.

SUSY ORIGIN OF NU-MASS

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

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

➡ **ATM SCALE**
SUSY-SEESAW



➡ SOLAR SCALE
RADIATIVE

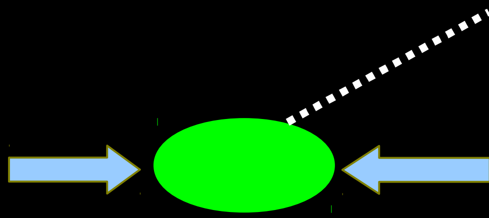
Diaz et al PRD68 (2003) 013009, PRD62 (2000) 113008
PRD65 (2002) 119901; PRD61 (2000) 071703
Bazzocchi et al arXiv:1202.1529

Lightest neutralino decays ➡ **GRAVITINO AS DM**

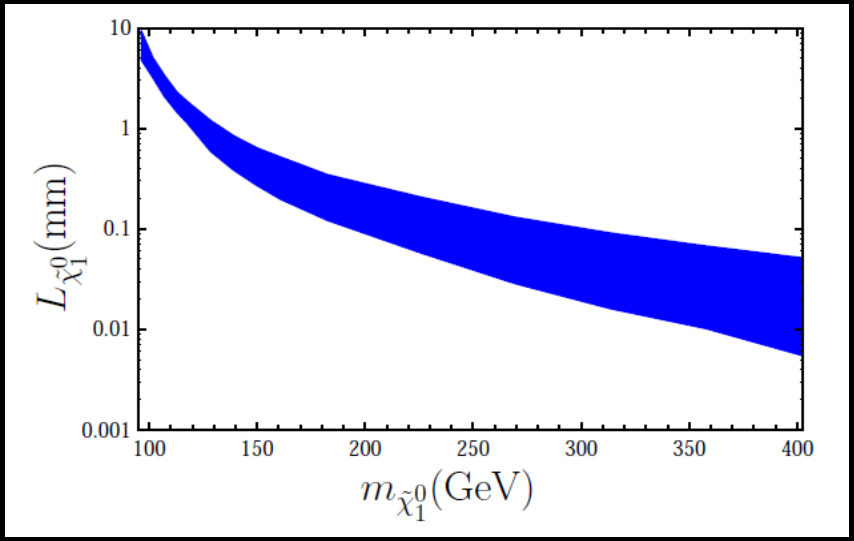
PROBING NUs AT LHC

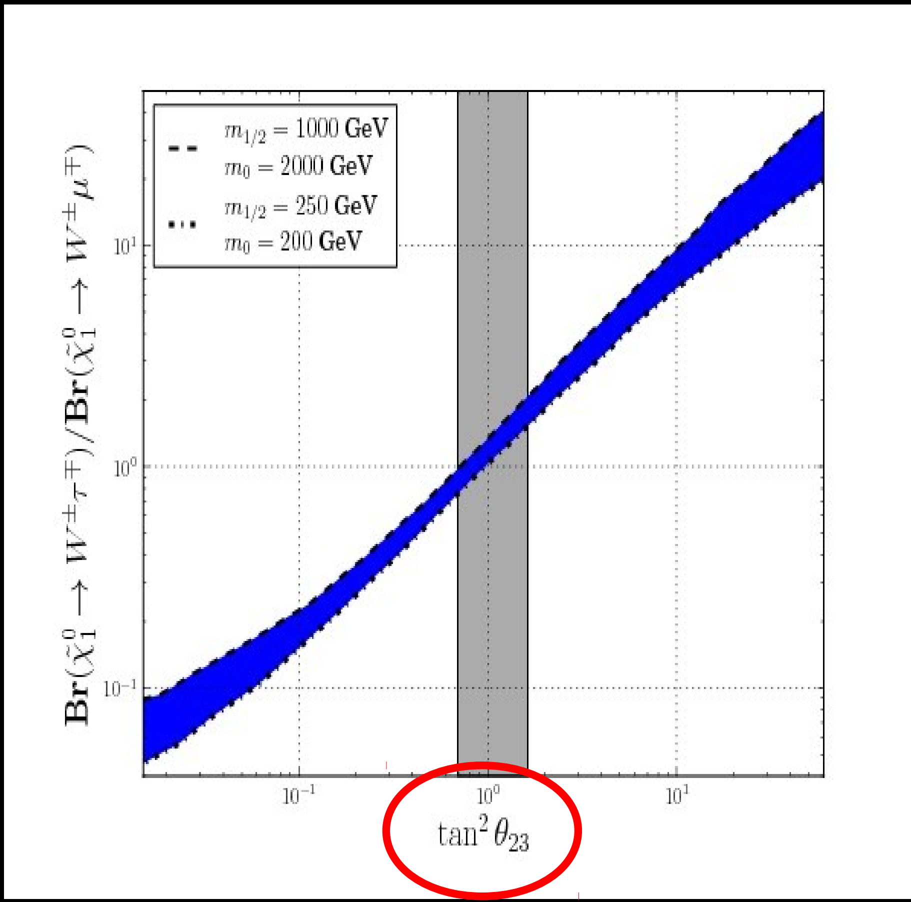
De Campos et al PRD82 (2010) 075002
JHEP 0805:048, 2008

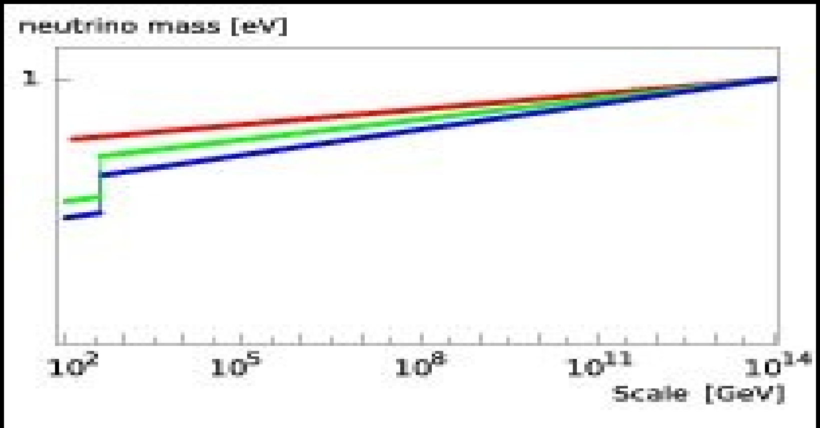
$\tilde{\chi}_1^0 \to W^{\pm} l_i^{\mp}$ $\tilde{\chi}_1^0 \to Z^0 \nu_i$



neutralino NLSP decays dominantly through RpV channels

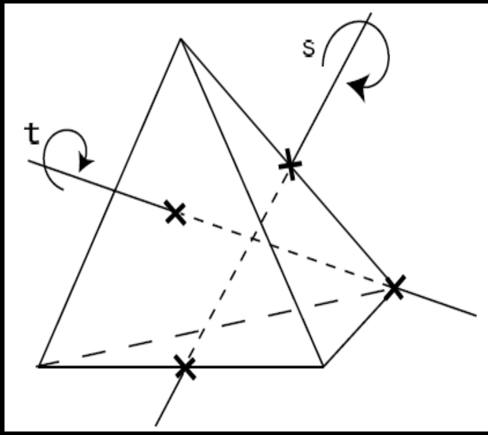






Babu et al   PLB552 (2003) 207
Hirsch et al PRD69 (2004) 093006

The flavor problem



A4

Z_3

$\langle\phi\rangle \sim (1,1,1)$

Sectors are separated by an extra Abelian Zn

Z_2

$\langle\phi'\rangle \sim (1,0,0)$

CHARGED LEPTONS

NEUTRINOS

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

Harrison, Perkins, Scott
Altarelli, Feruglio NPB B720 (2005) 64
Lindner et al TBM deviations-RGE

NON-ABELIAN FLAVOR ROADMAP

Ishimori,et al Prog Theor Phys Suppl 183 (2010) 1 stringy origin? Nilles, Raby, ...

Hirsch et al arXiv:1201.5525 FLASY2011

Frampton and Kephart, PRD64 (01)

order	groups
6	$S_3 \equiv D_3$
8	$D_4, Q = Q_4$
10	D_5
12	$D_6, Q_6, T \equiv A_4$
14	D_7
16	$D_8, Q_8, Z_2 \times D_4, Z_2 \times Q$
18	$D_9, Z_3 \times D_3$
20	D_{10}, Q_{10}
22	D_{11}
24	$D_{12}, Q_{12}, Z_2 \times D_6, Z_2 \times Q_6, Z_2 \times T, Z_3 \times D_4, Z_3 \times Q, Z_4 \times D_3, S_4$
26	D_{13}
28	D_{14}, Q_{14}
30	$D_{15}, D_5 \times Z_3, D_3 \times Z_5$

A4

Babu, Ma, Valle PLB552 (2003)
Altarelli, Feruglio NPB72 (2005)
Hirsch, Morisi, Valle PRD78 & D79 (2008) & PLB679 (2009) 454
Hagedorn, Molinaro, Petcov (2009)
Ibanez, Morisi, Valle, PRD80 (2009)

S3

Grimus, Lavoura, JHEP0904
Mohapatra, Nasri, Yu, PLB627
Mondragón, Mondragón, Peinado

S4

Lam PRL101
Bazzocchi, Morisi, PRD80

T'

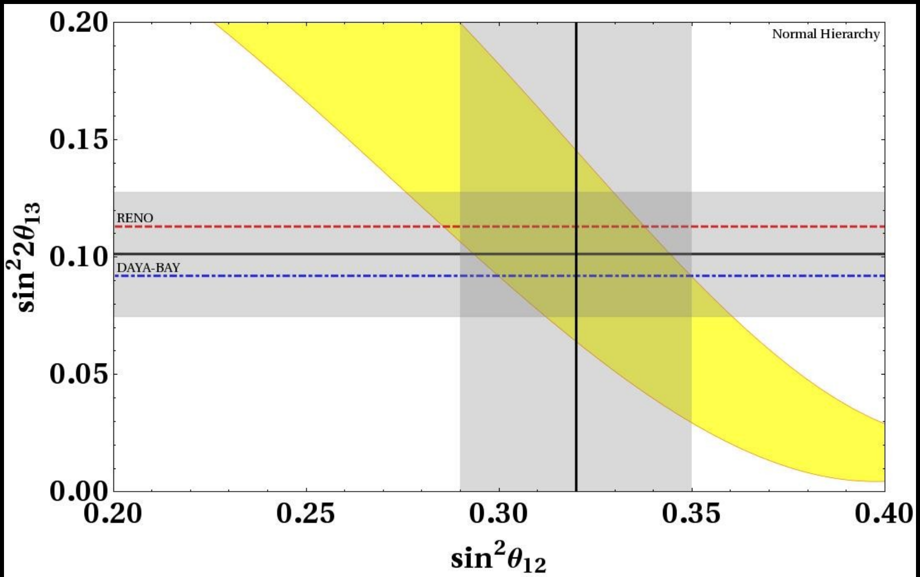
Feruglio, Hagedorn, Lin, Merlo (2007)
Carr, Frampton (2007)
Aranda, Carone, Lebed PLB474

D27

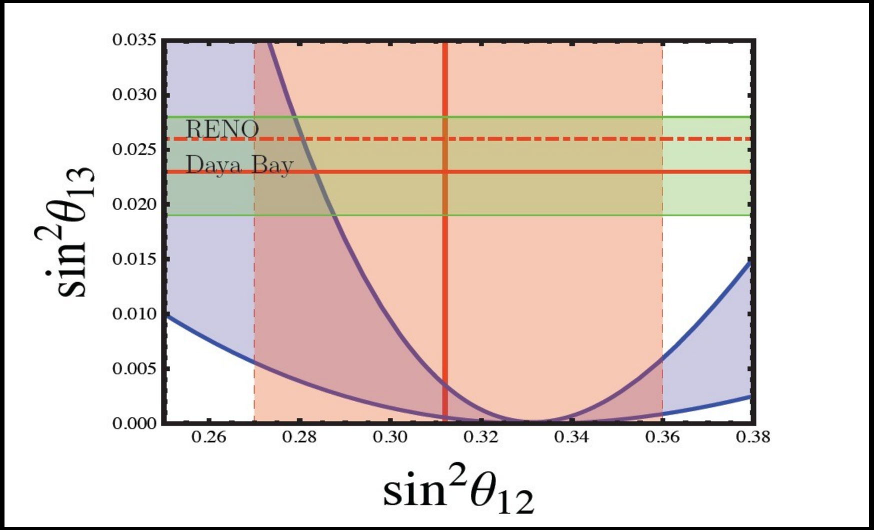
Medeiros, King, Ross PLB648

....

OSCILLATION PARAMETER CORRELATIONS **LARGE THETA13**



Boucenna, et al arXiv:1204.4733



Dorame, et al : arXiv:1203.0155

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

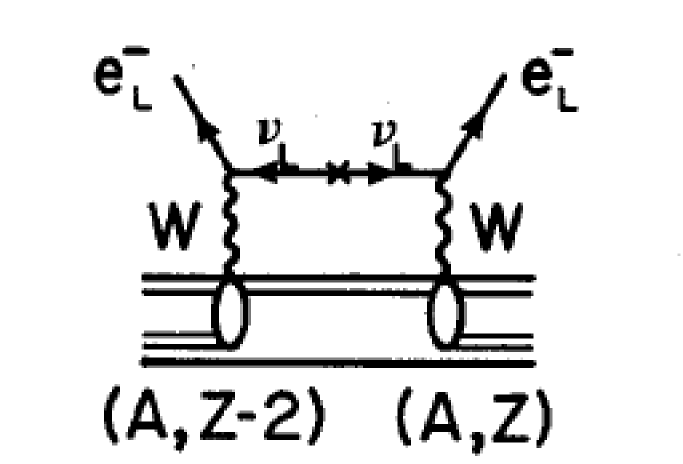
Relating quarks and leptons without grand unification

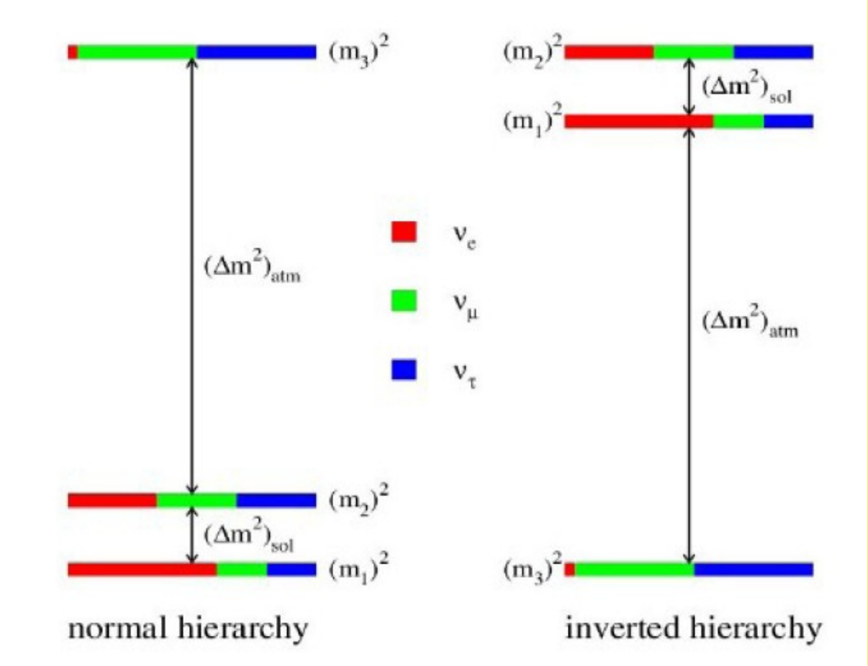
S. Morisi,[1,*] E. Peinado,[1,†] Yusuke Shimizu,[2,‡] and J. W. F. Valle[1,§]

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

TESTING NEUTRINO SPECTRA W/ NU-LESS DBD

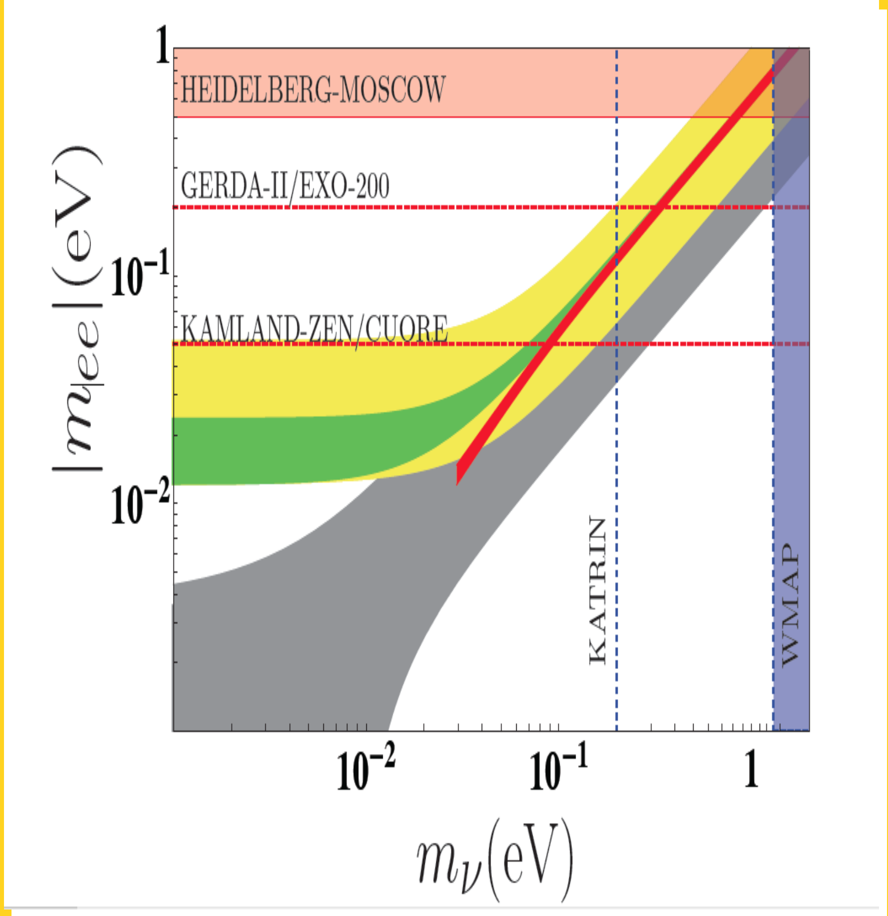
NH VERSUS IH





Flavor sensitivity

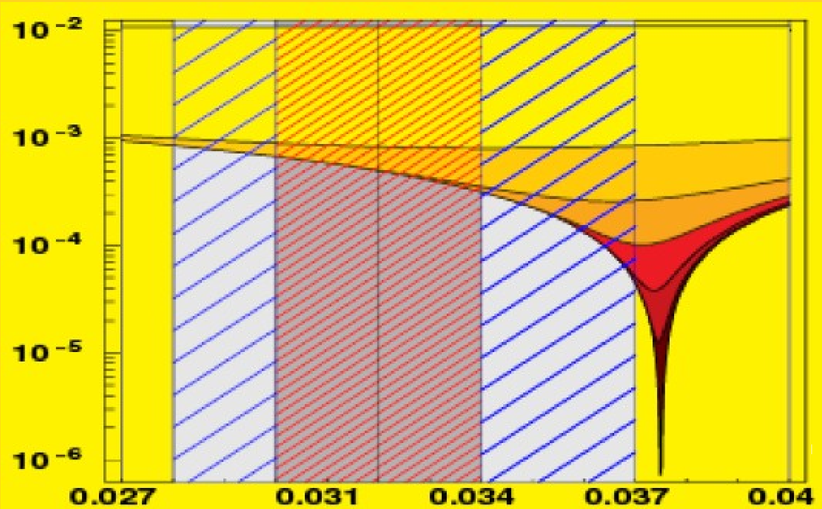
Boucenna, et al arXiv:1204.4733
*KamLAND-Zen arXiv:1205.6130



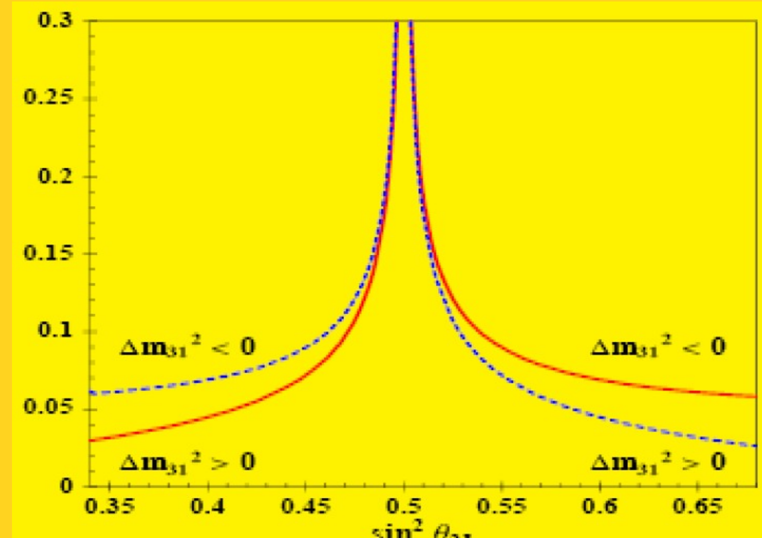
FLAVOR SYMMETRY & DBD

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

PRD78:093007 (2008)

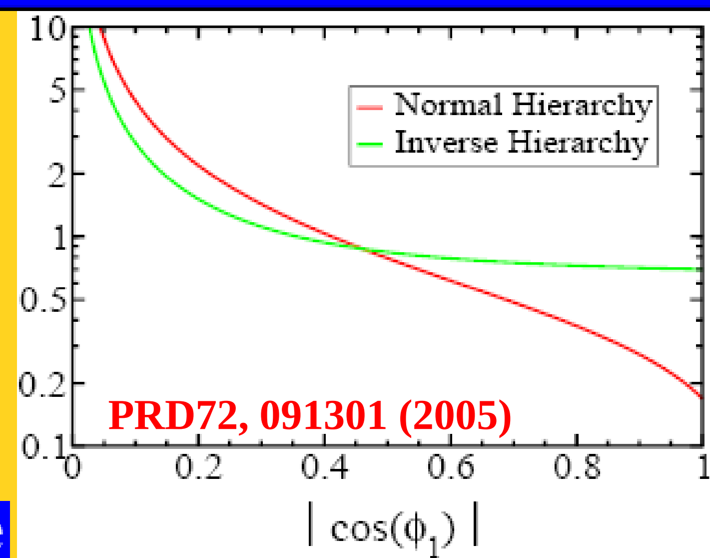


correlates with $\alpha = \frac{\Delta m^2_{\rm SOL}}{\Delta m^2_{\rm ATM}}$



correlates with ATM angle

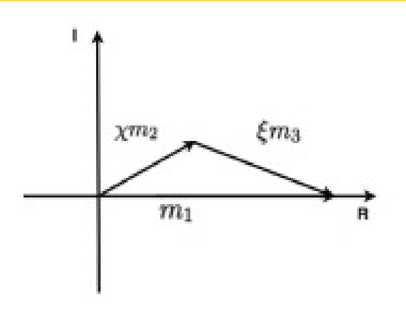
A4



correlates with Majorana phase

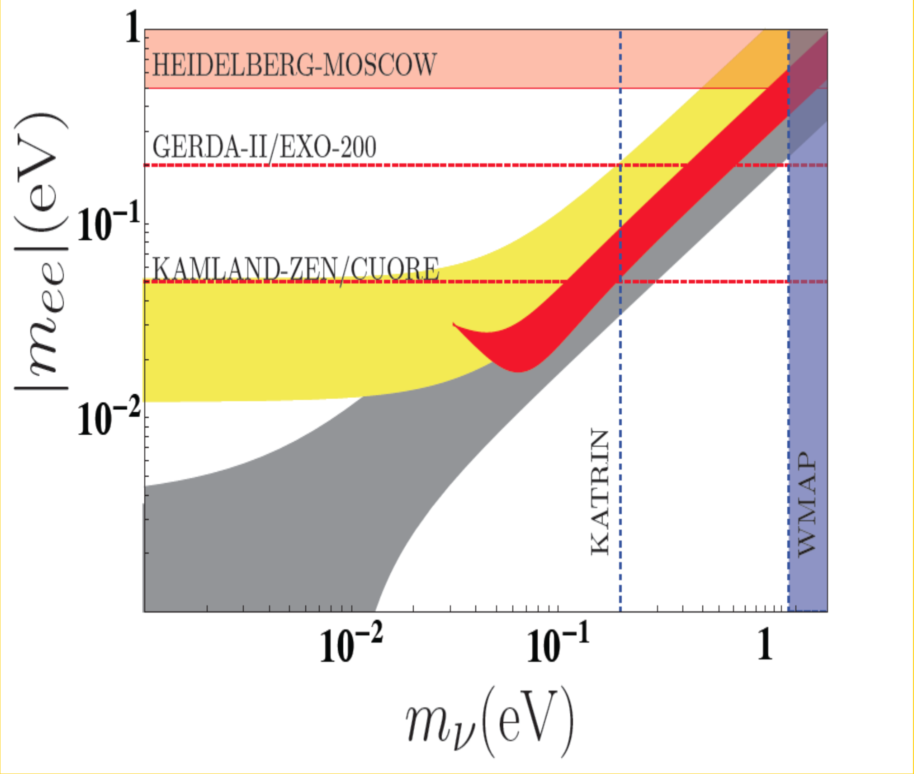
NEUTRINO MASS SUM RULES

Rodejoham & Barry
NPB842 (2011) 33

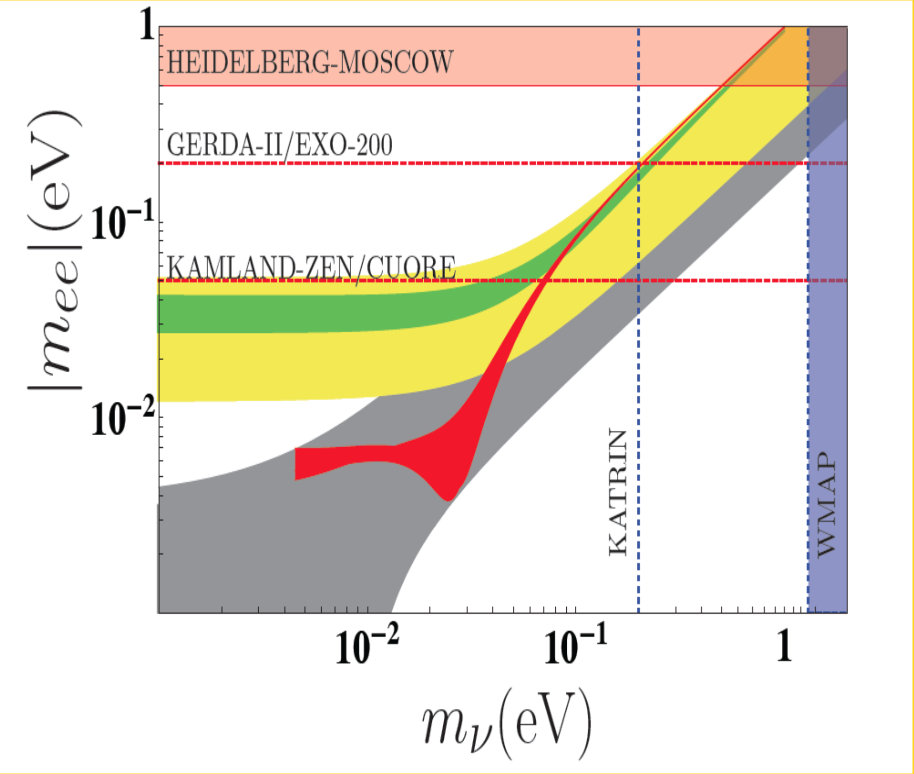


LOWER BOUND(s) ON 0-NU DBD

Dorame et al NPB861 (2012) 259-270

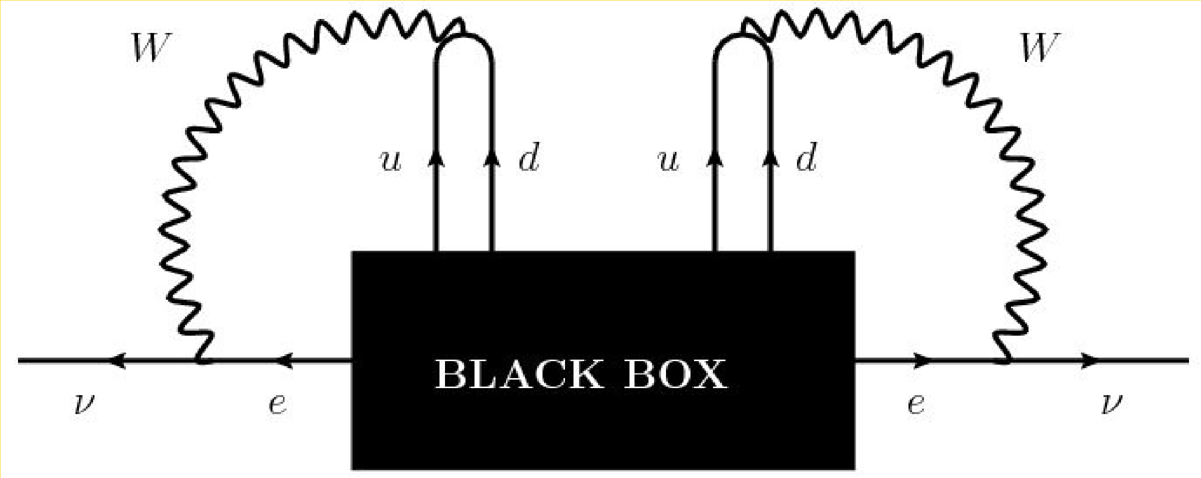


Dorame et al arXiv:1203.0155

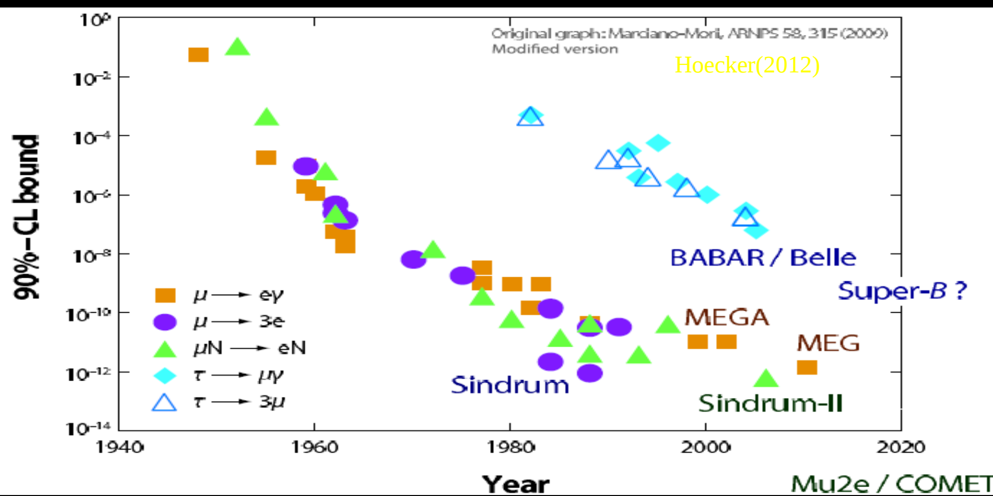


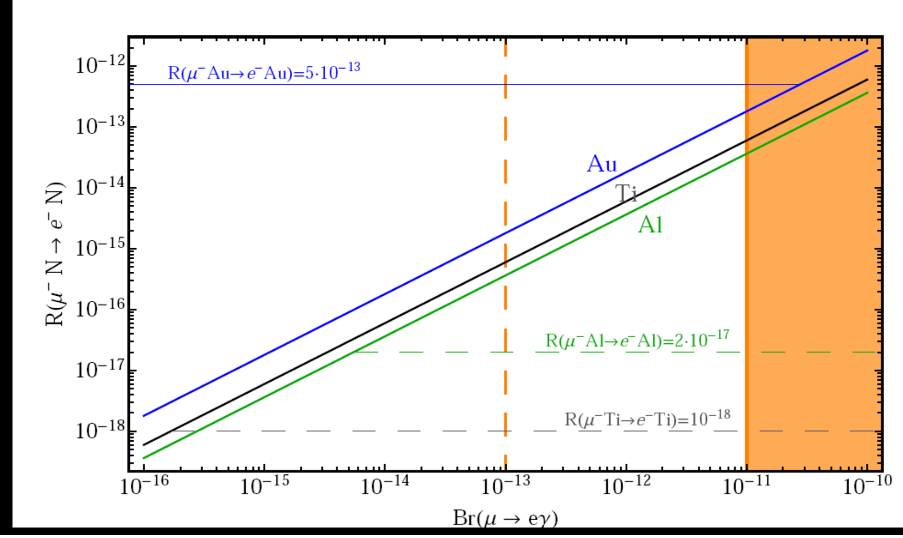
SIGNIFICANCE OF NEUTRINOLESS DBD

0-nu DBD ➡ **MAJORANA**



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





LFV/CPV survive as m-nu → 0 hence unsuppressed by m-nu

NHL vs SUSY exchange

Hall, Kostelecky & Raby;Borzumati, Masiero
Casas, Ibarra; Herrero etal; Bernabeu etal; Deppish et al PRD72 (2005) 036001; NPB752 (2006) 80
Hirsch, et al PLB679 (2009) 454
Ibanez Morisi JV PRD80 (2009) 053015
Hirsch et al PRD 78 (2008) 013006
Esteves et al JHEP05 (2009) 3

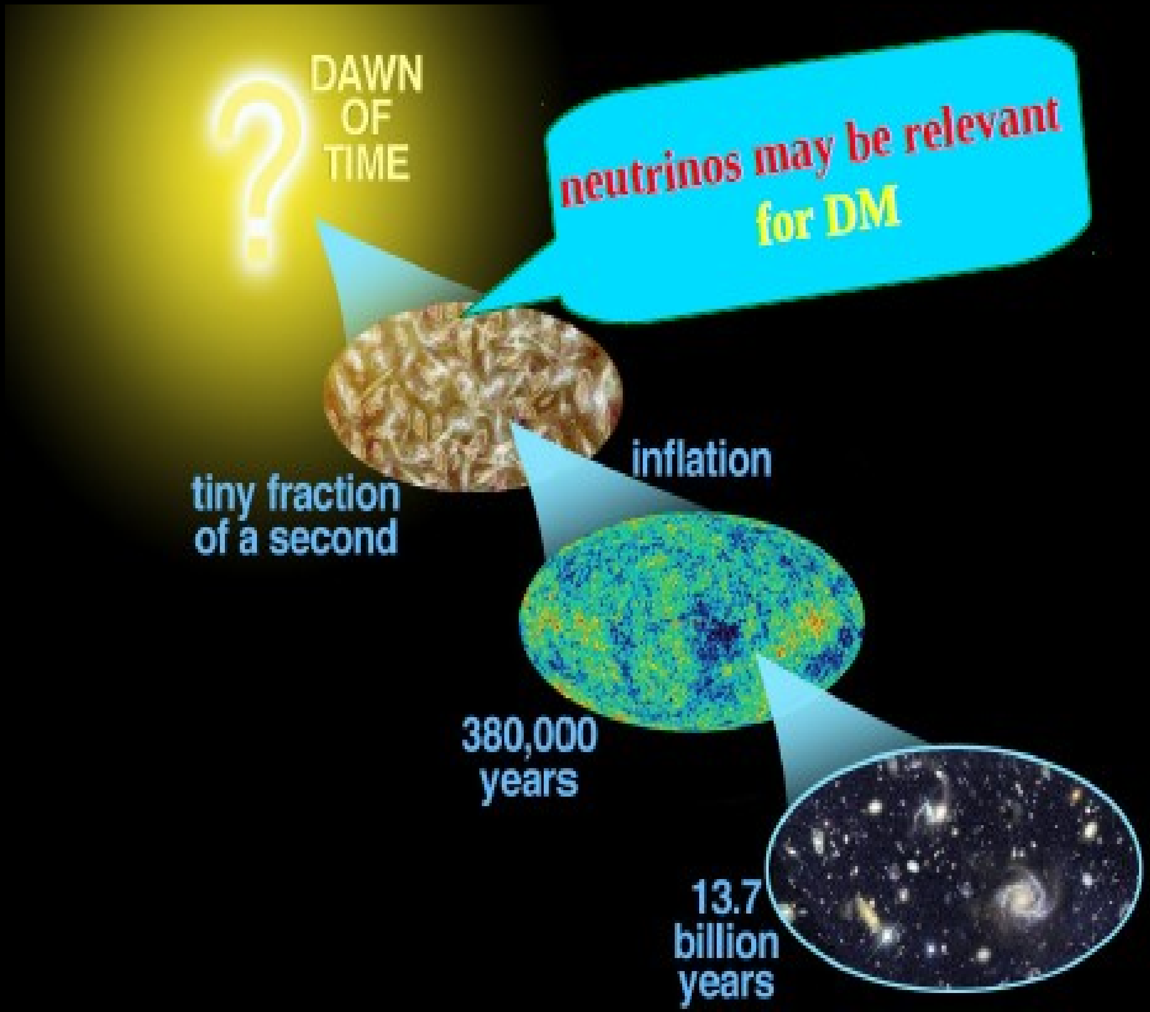
LFV NSI

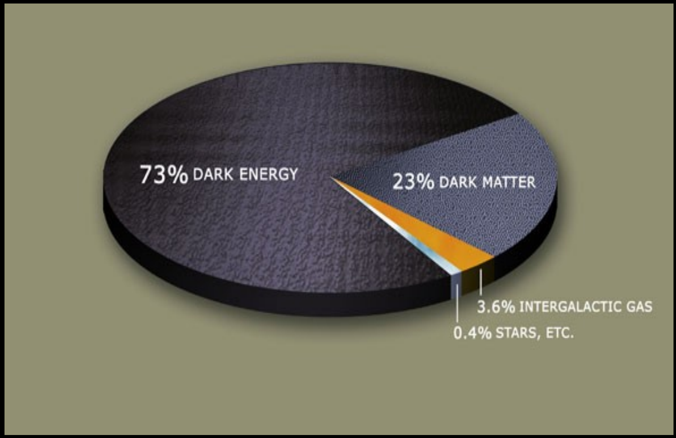
Forero et al JHEP 1109 (2011) 142

Process	$\mu \to e\gamma$		$\tau \to e\gamma$		$\tau \to \mu\gamma$	
Hierarchy	NH	IH	NH	IH	NH	IH
$\lvert\eta^l_{12}\rvert <$	1.4×10^{-3}	1.4×10^{-3}	2.8×10^{-2}	2.8×10^{-2}	2.8×10^{-2}	2.8×10^{-2}
$\lvert\eta^l_{13}\rvert <$	2.0×10^{-2}	$2.1(1.6)\times10^{-2}$	1.1×10^{-2}	1.1×10^{-2}	3.1×10^{-2}	3.2×10^{-2}
$\lvert\eta^l_{23}\rvert <$	$2.7(2.1)\times10^{-2}$	$2.5(1.9)\times10^{-2}$	6.4×10^{-2}	4.3×10^{-2}	1.2×10^{-2}	1.2×10^{-2}
$\lvert\eta^L_{12}\rvert <$	$11.0(9.6)\times10^{-4}$	$1.5(1.1)\times10^{-3}$	5.1×10^{-2}	5.2×10^{-2}	5.3×10^{-2}	5.7×10^{-2}
$\lvert\eta^L_{13}\rvert <$	$3.1(2.7)\times10^{-2}$	3.3×10^{-2}	1.1×10^{-2}	1.0×10^{-2}	4.8×10^{-2}	4.8×10^{-2}
$\lvert\eta^L_{23}\rvert <$	$2.8(2.2)\times10^{-2}$	3.0×10^{-2}	5.5×10^{-2}	5.4×10^{-2}	1.2×10^{-2}	1.2×10^{-2}

Table 1. Limits on unitarity violation parameters from lepton flavor violation searches. The numbers given in parenthesis correspond to the improvement obtained with the recent MEG limit on $\mu \to e\gamma$. Other entries in the table are unchanged. These limits express the correlation between lepton non-unitarity and LFV that holds in low-scale seesaw schemes under a "minimal flavor violation hypothesis" defined in the text.

NEUTRINO DARK MATTER CONNECTION



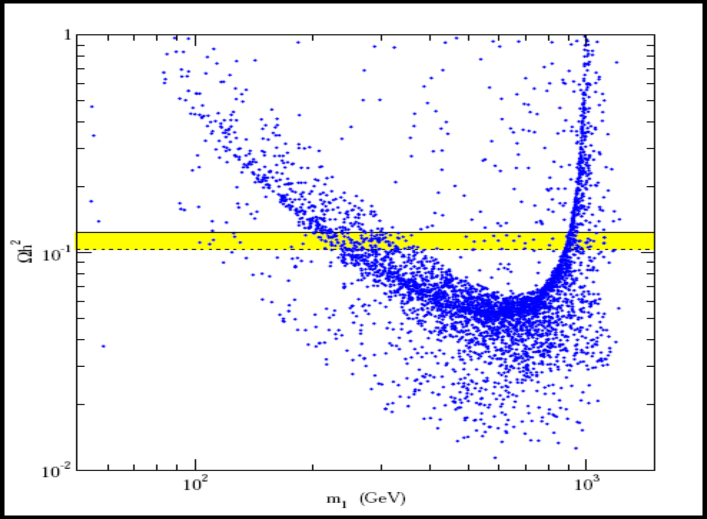


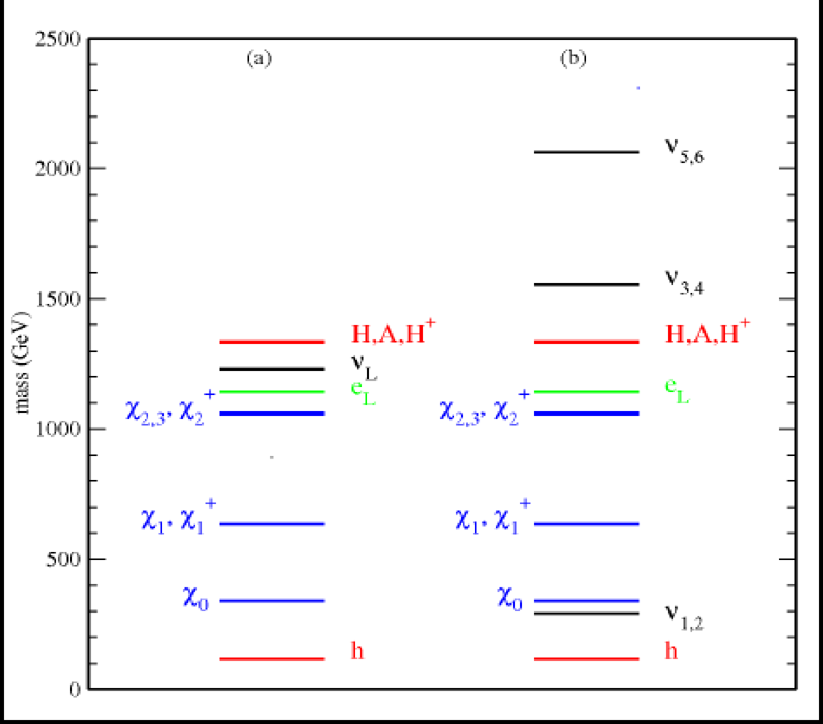
Talks by
Hannestad
Profumo
Melchiorri

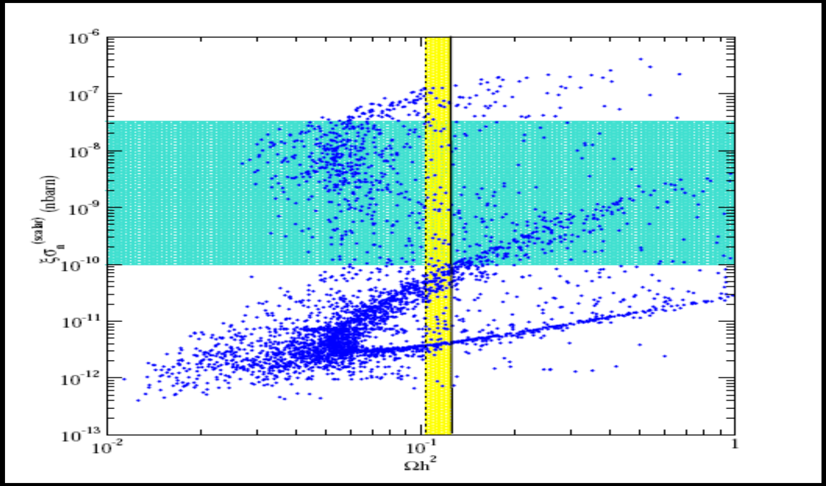
Even if **not** the source **neutrinos may give the clue to DM**

Neutrinos masses may change SUSY spectrum giving SNEUTRINO-like DM

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







DM STABILITY: ACCIDENT Lavoura, Morisi, Valle. arXiv:1205.3442

From FLAVOUR SYMMETRY NEUTRINO MIXING

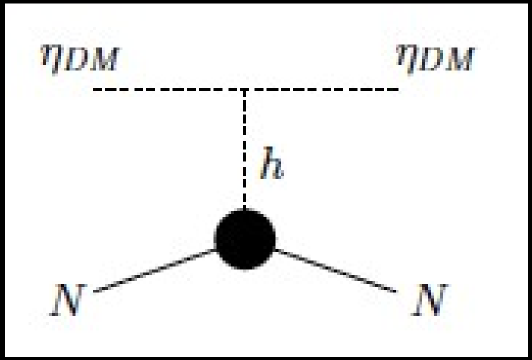
A4

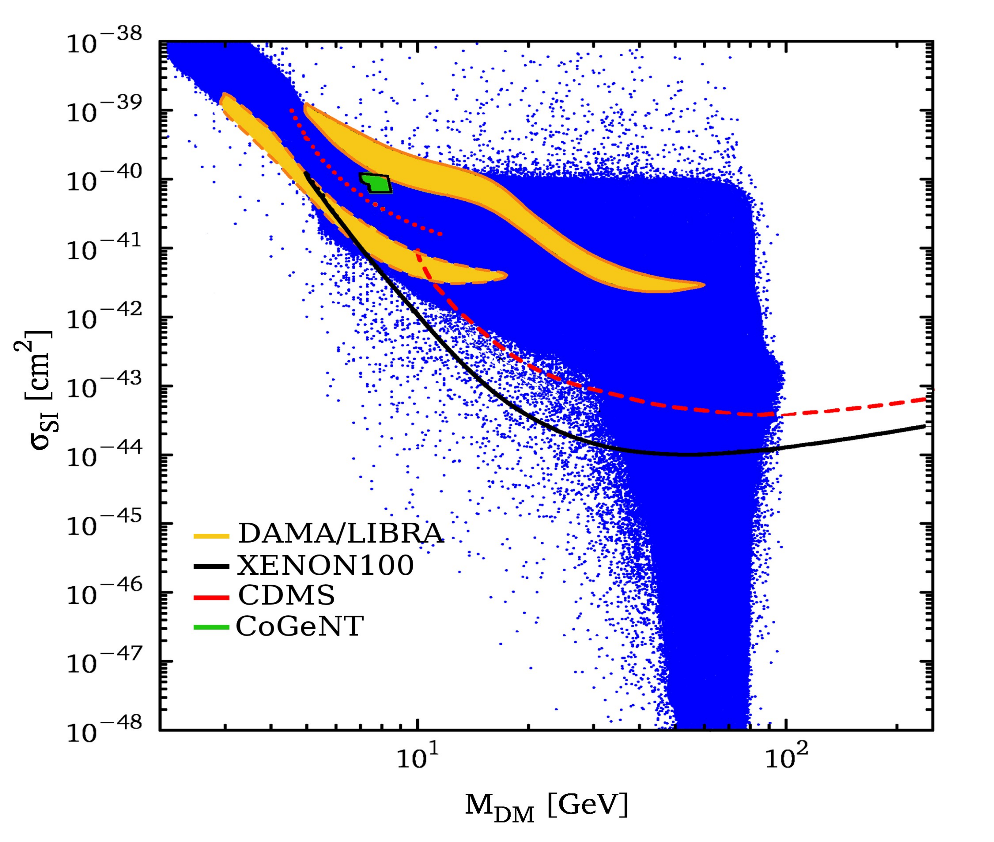
Hirsch, Morisi, Peinado, Valle
PRD82 116003 (2010)

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

BROKEN TO **Z2** SYMMETRY

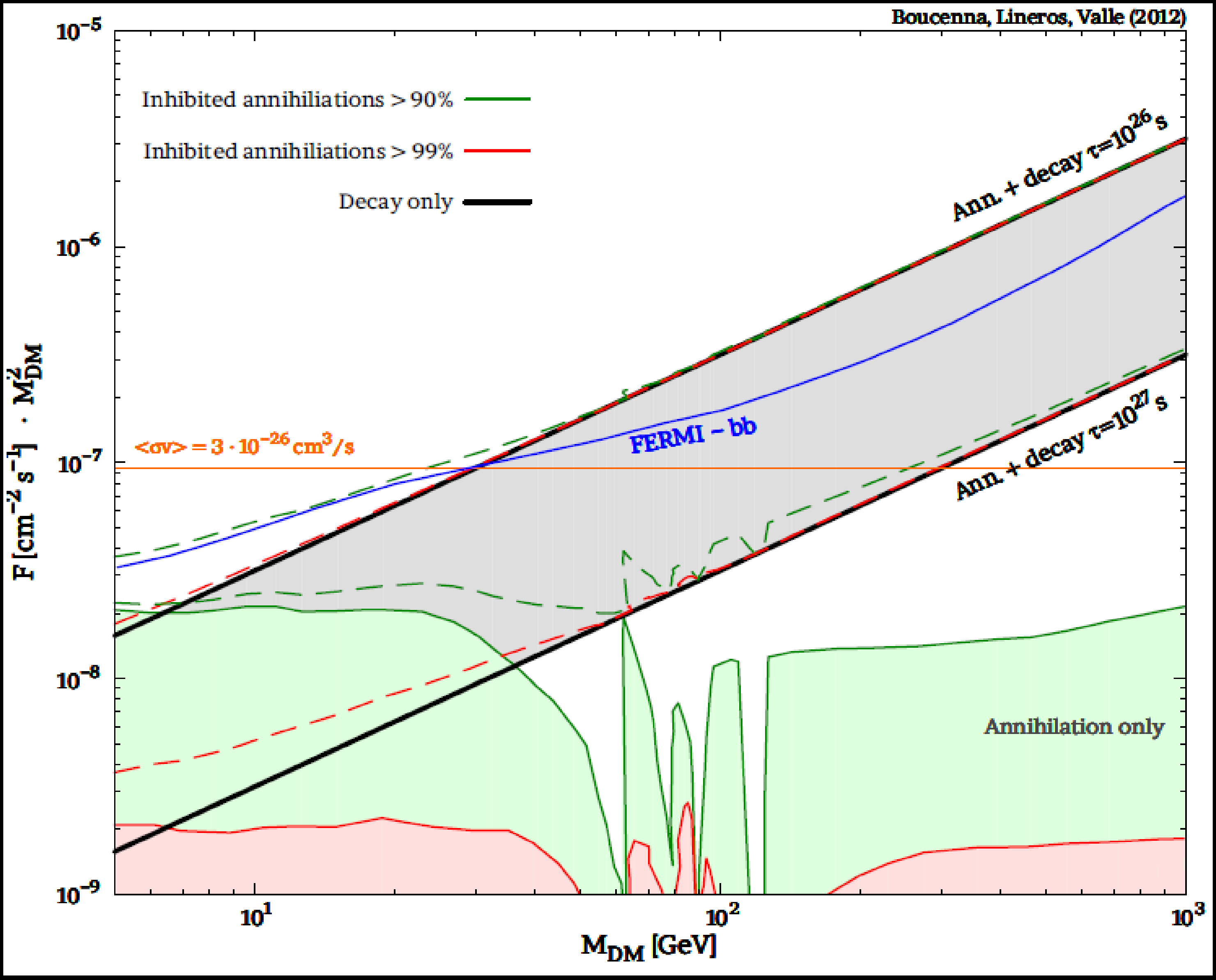
HIGGS PORTAL
DM DETECTION





Dark matter not strictly stable

Berezinsky et al PRD57 (1998)147 Coleman 88, Kallosh, Linde, Susskind, Nelson, Seiberg, ...



arXiv:1204.2576

WIMP DIRECT DETECTION SUPPRESSED

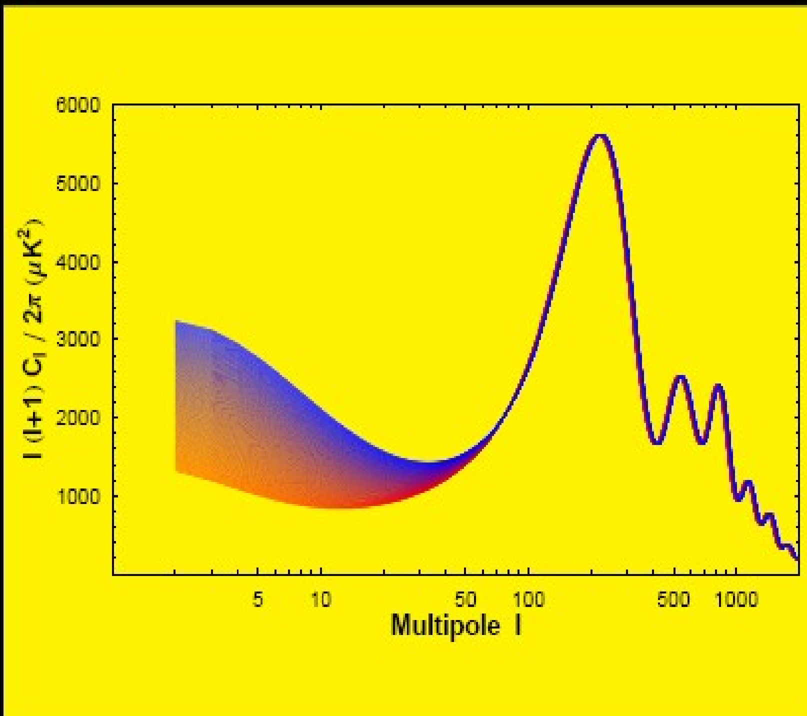
WIMP INDIRECT DETECTION ENHANCED

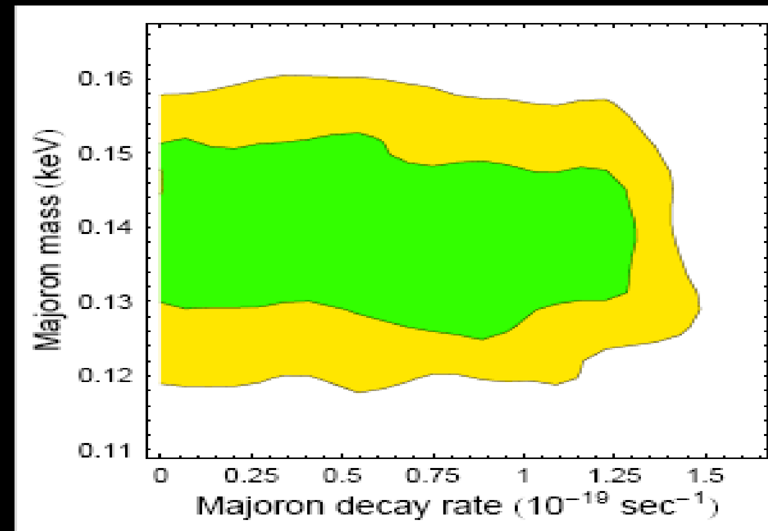
Majoron decaying dark matter

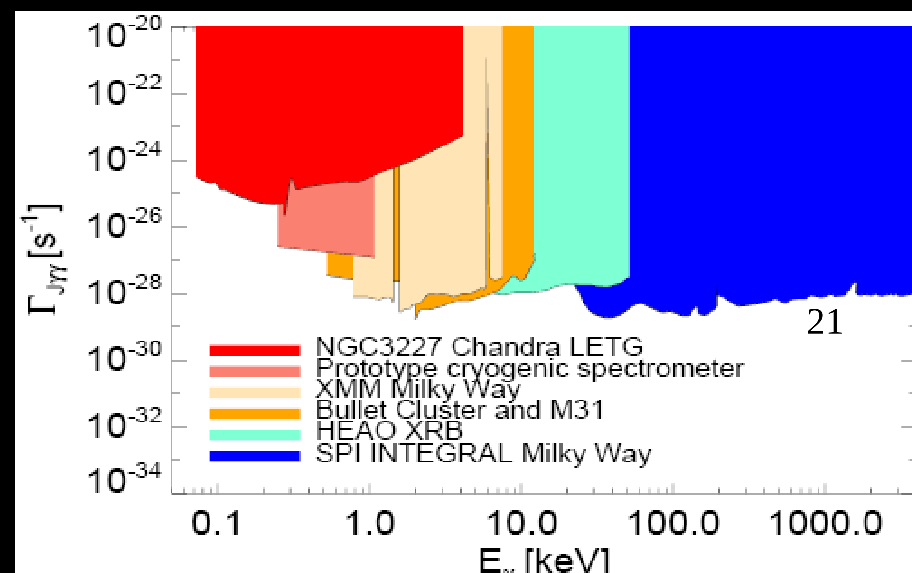
Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

Lattanzi & Valle, PRL99 (2007) 121301

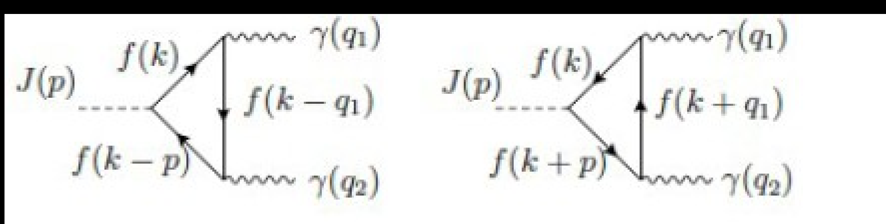






Esteves et al, PRD 82, 073008 (2010)

Bazzocchi & al JCAP 0808 (2008) 013



Gravitino as decaying dark matter **BRPV**

decays suppressed by Planck mass & smallness of m-nu

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

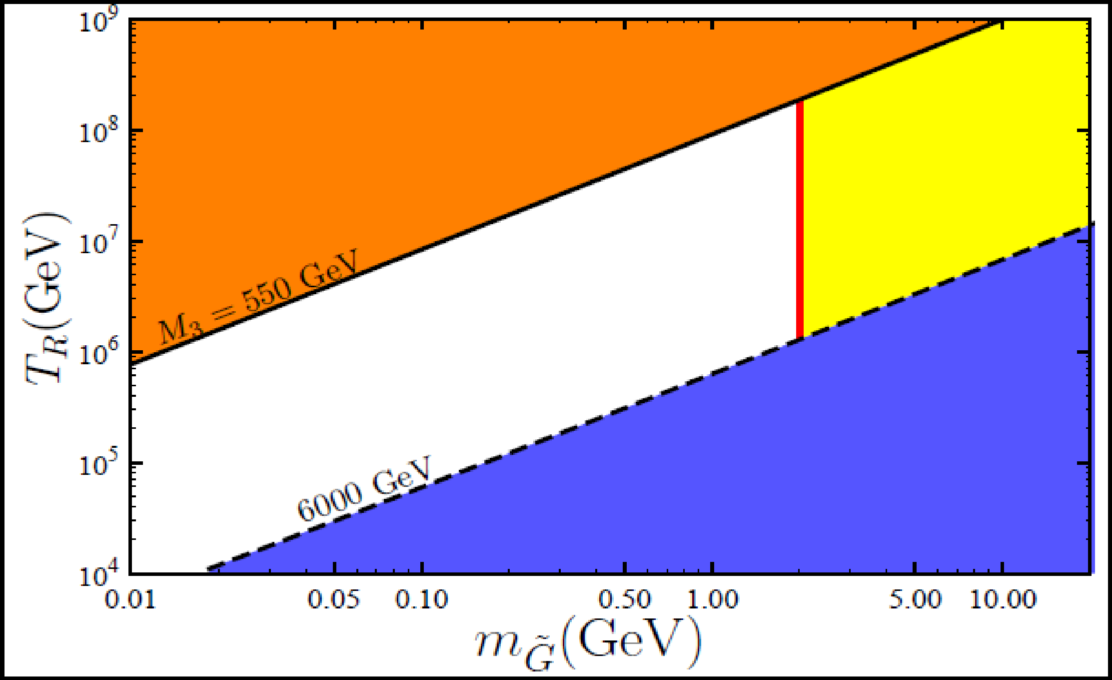
chosen to fit neutrino osc. data

Restrepo et al
PRD85 (2012) 023523

relic abundance

+ Susy searches

excluded by gamma line searches @ Egret & Fermi-LAT



Vertongen & Weniger

SUMMARY

OSCILLATIONS MAINLY ROBUST

ORIGIN OF NEUTRINO MASS & **MIXING PATTERN: MISTERY**

DARK MATTER MAY NOT BE STABLE

DARK MATTER MAY RELATE TO NEUTRINOS

- sneutrino-like DM in inverse seesaw
- DM stability related to flavor symmetry
- majoron as Decaying DARK MATTER
- 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