Updating the Status of Neutrino Physics

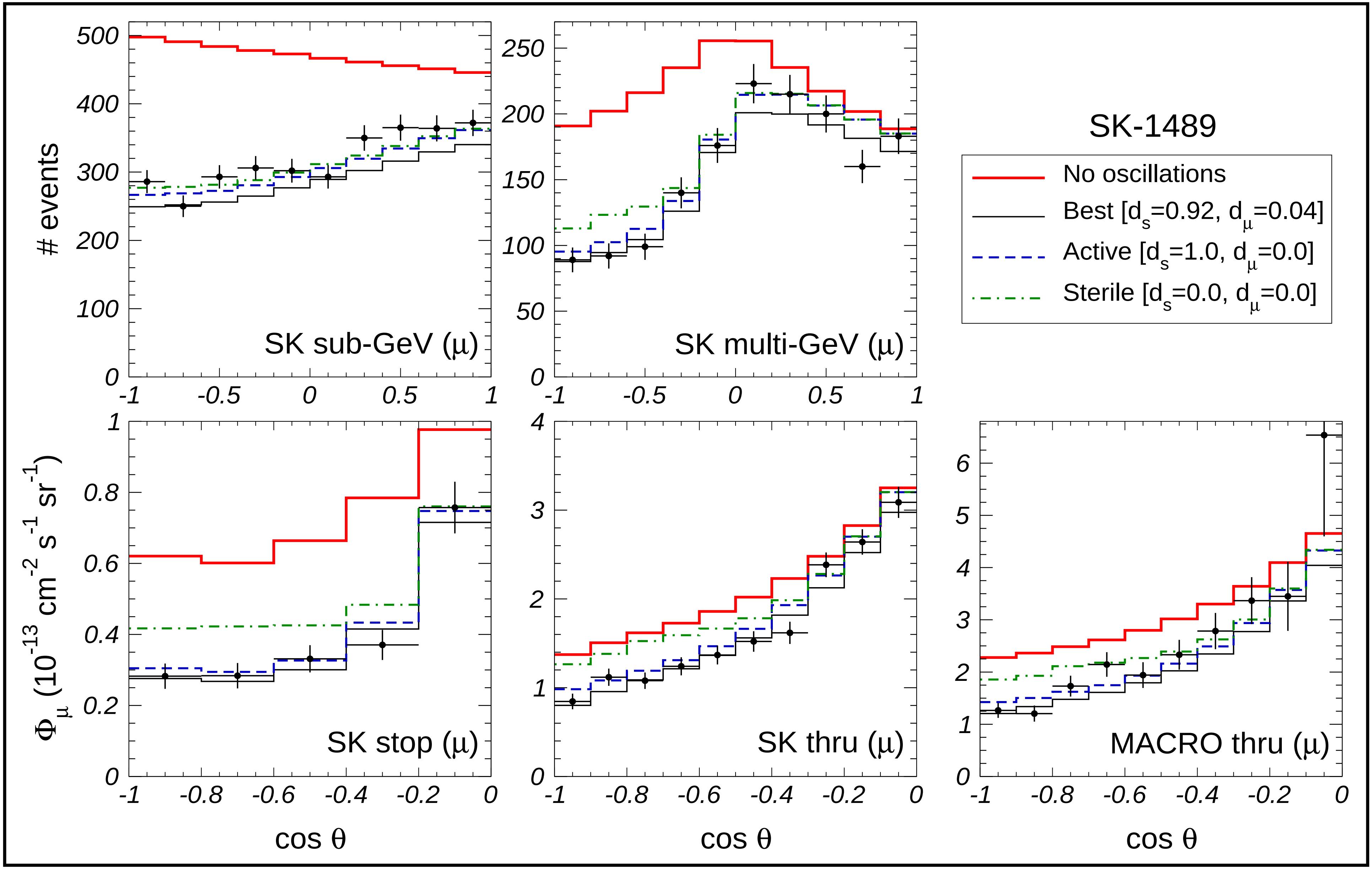
J. W. F. Valle

IFIC-CSIC/U. Valencia

Based on
hep-ph/0301061 and hep-ph/0307192

Atmospheric zenith distribution

Maltoni, Schwetz, Tortola and JV PRD67 (2003) 013011



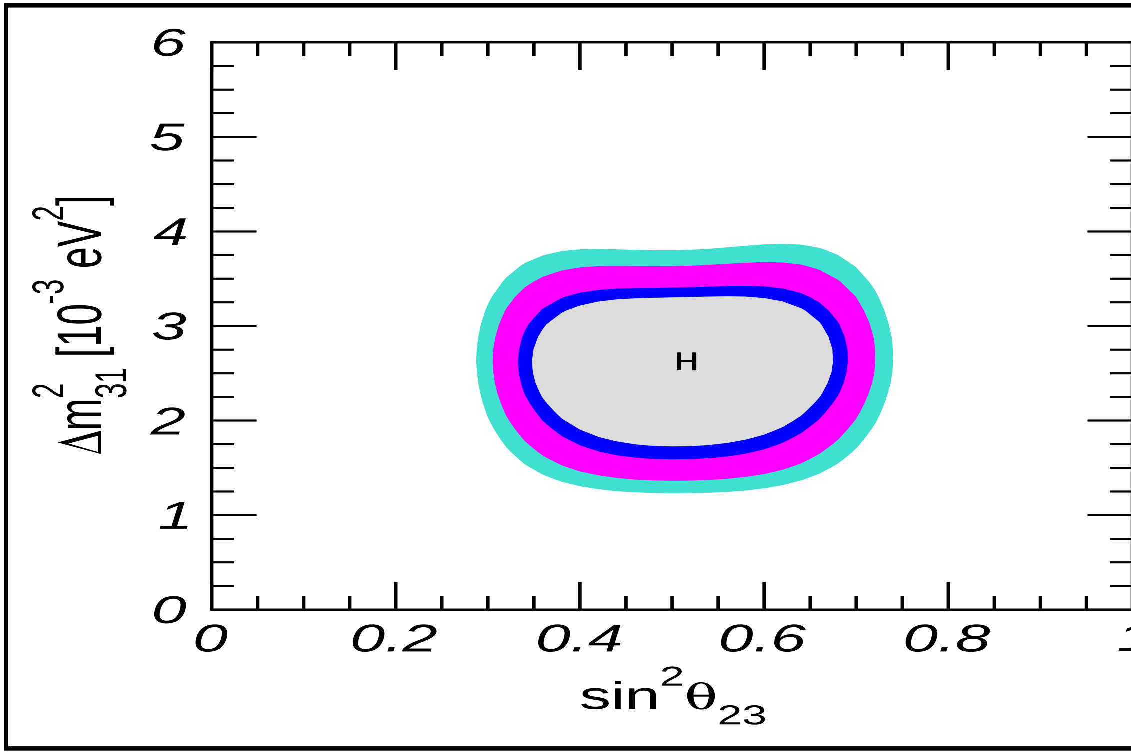
atmospheric neutrino parameters-1

- sterility rejection

Maltoni et al PRD67 (2003) 013011
hep-ph/0207227

$\sin^2\theta_{\rm ATM} = 0.5$

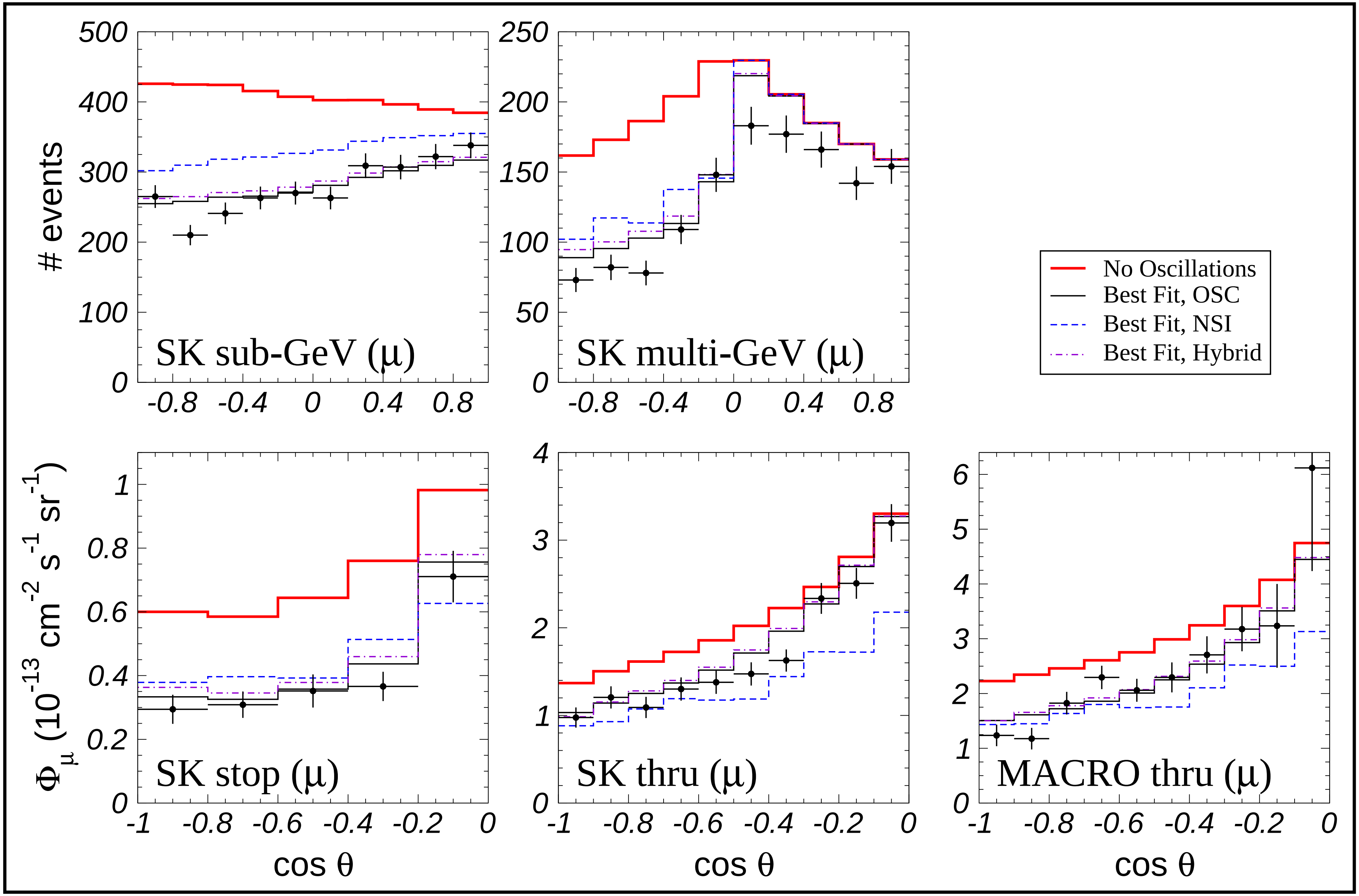
$\Delta m^2_{\rm ATM} = 2.5 \times 10^{-3}\ {\rm eV}^2$



light-dark or normal/inverted symmetry

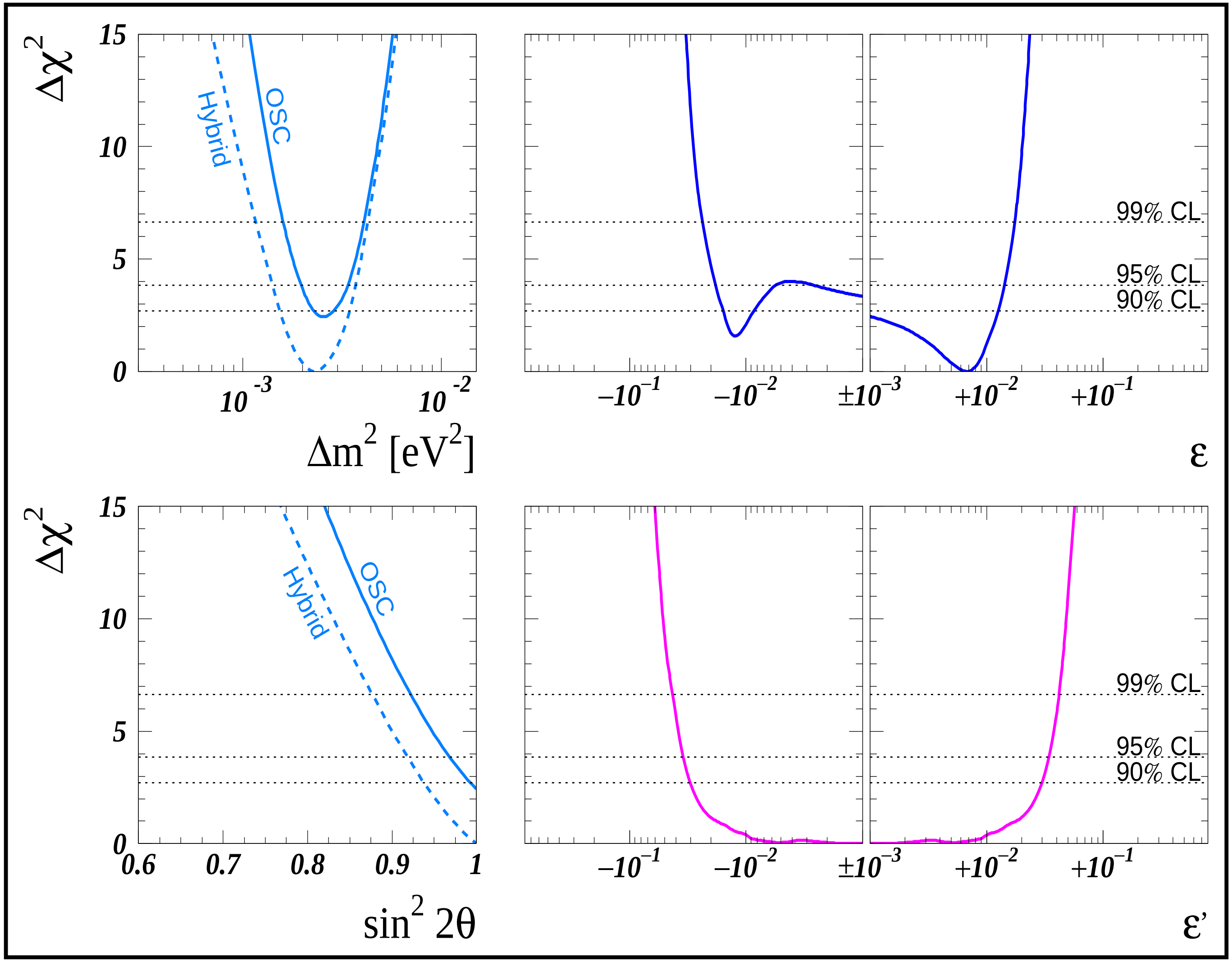
How robust are atmospheric oscillations?

very good contained atm-fit, Gonzalez-Garcia et al, PRL **82** (1999) 3202



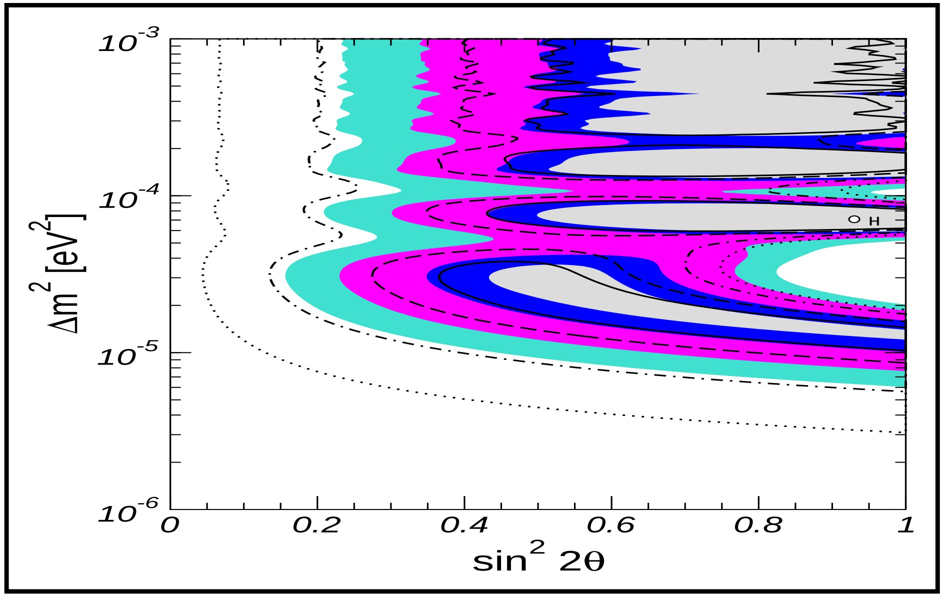
non-standard interactions vs atm data

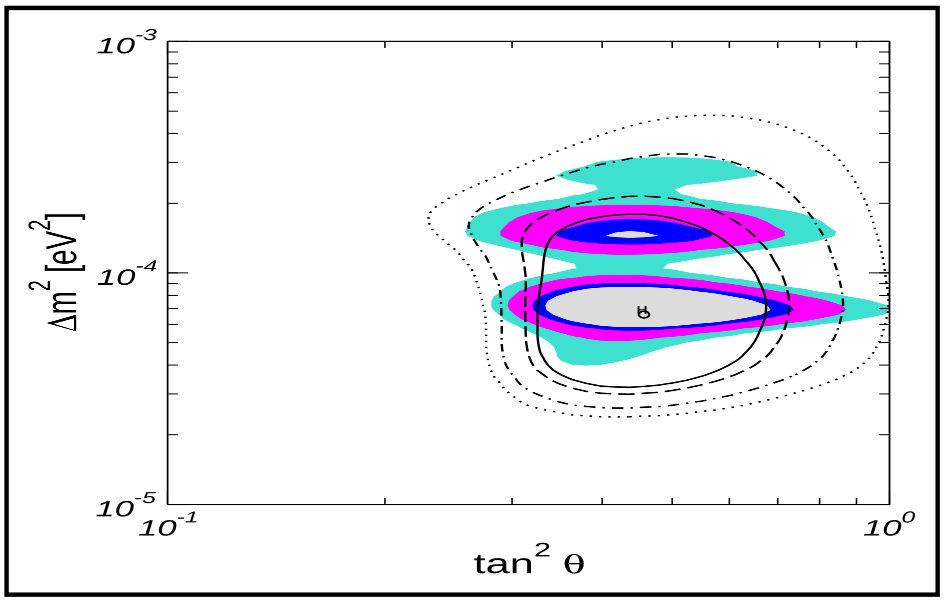
Fornengo et al,
PRD **65** (2002) 013010
[hep-ph/0108043].



atm bounds on FC and NU nu-interactions

Solar + KamLAND reactor results





Maltoni, Schwetz & JV, PRD67 (2003) 093003 [hep-ph/0212129]

first 145-days data support oscillation hypothesis

critique of various analyses
S. Pakvasa and JV hep-ph/0301061

combining with solar neutrino data sample rules out non-LMA-MSW solutions

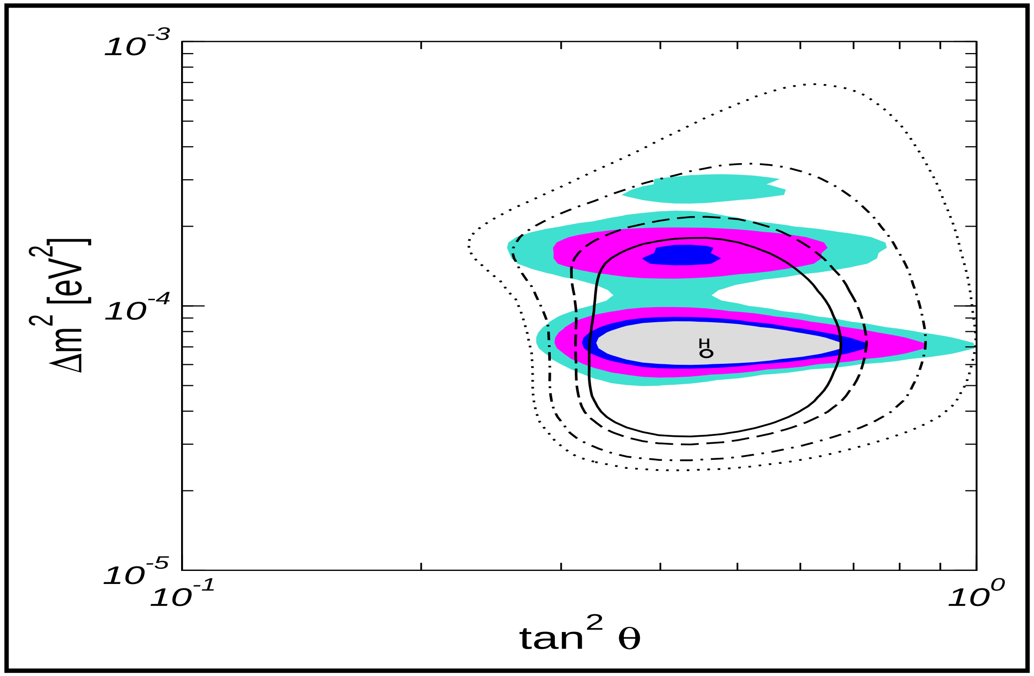
oscilllations happen inside the sun!

$0.29 \leq \tan^2\theta \leq 0.86$

5.1×10^{-5} eV$^2 \leq \Delta m^2_{\rm SOL} \leq 9.7 \times 10^{-5}$ eV^2

1.2×10^{-4} eV$^2 \leq \Delta m^2_{\rm SOL} \leq 1.9 \times 10^{-4}$ eV^2

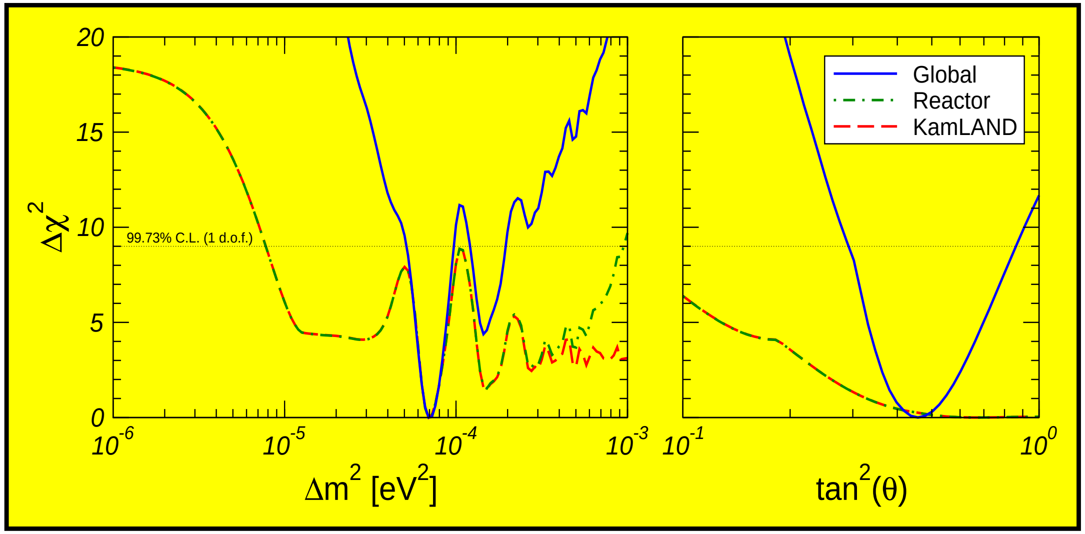
Solar + KamLAND results



Maltoni, Schwetz, JV, PRD67 (2003) 093003

consistency with Poisson method

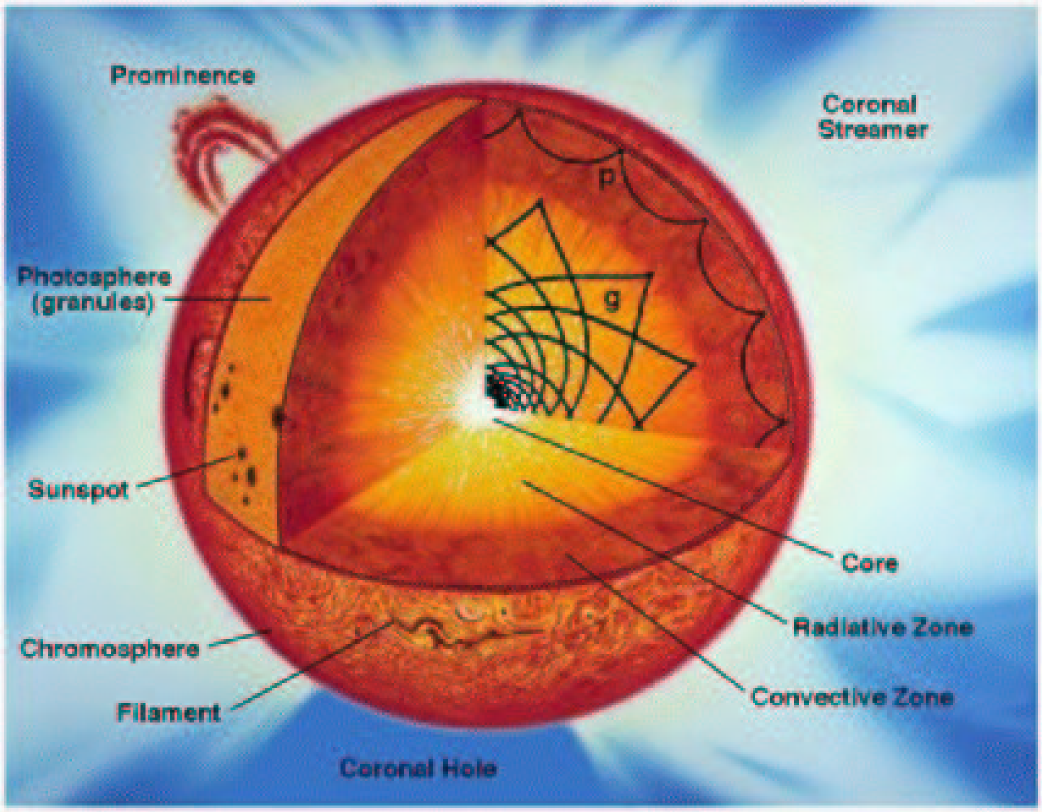
enormous progress wrt pre-KamLAND

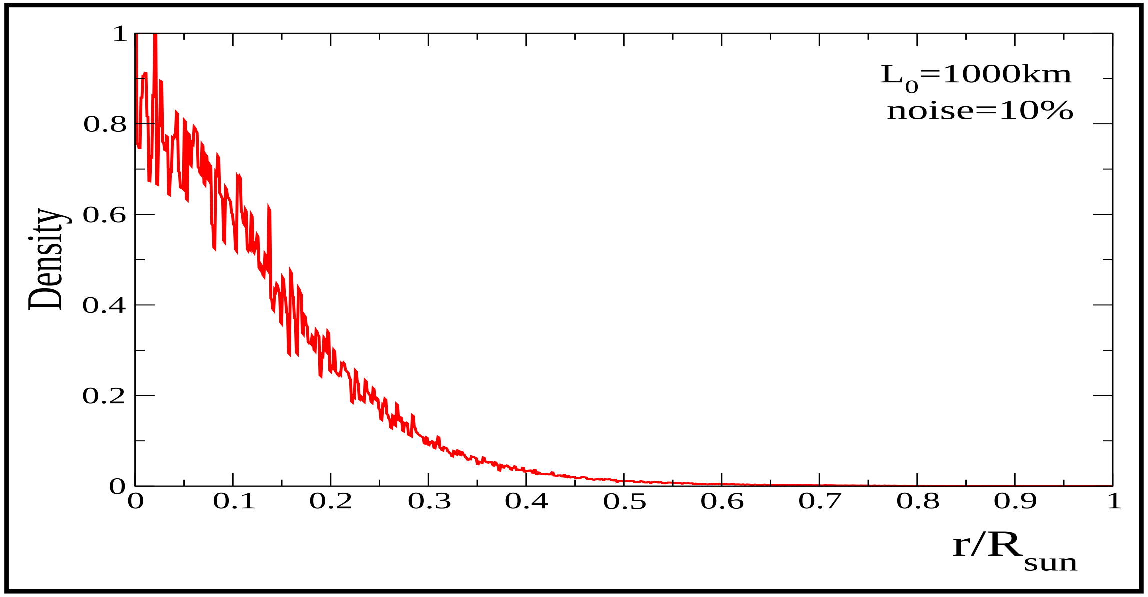


in contrast to atmospheric, solar mixing significantly non-maximal

bi-maximal models rejected

do we understand the Sun?





Robustness of MSW plot

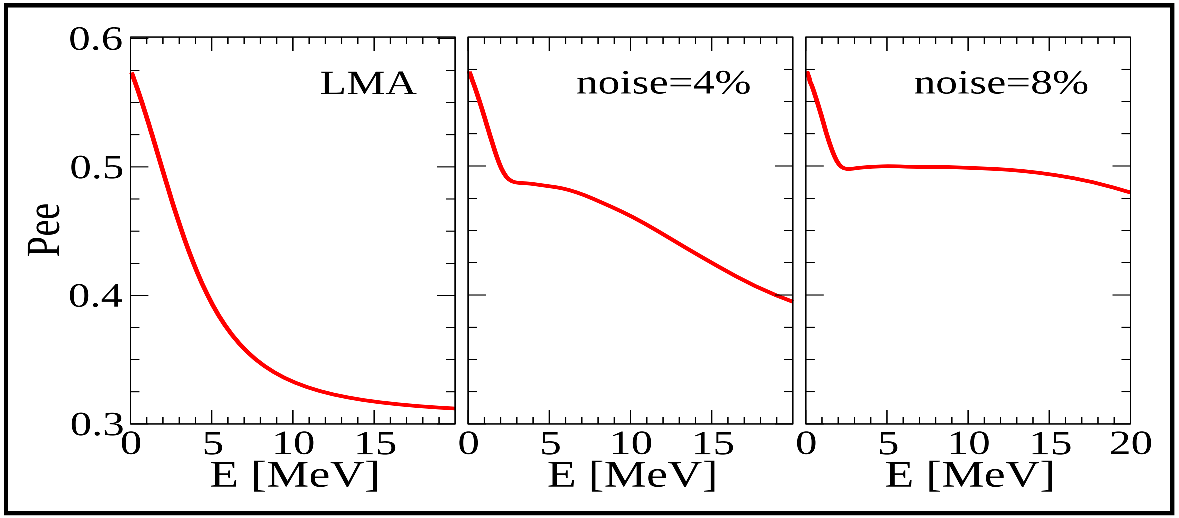
Burgess et al, Astrophys.J.588:L65,2003 [hep-ph/0209094]

neutrino propagation strongly affected by density noise

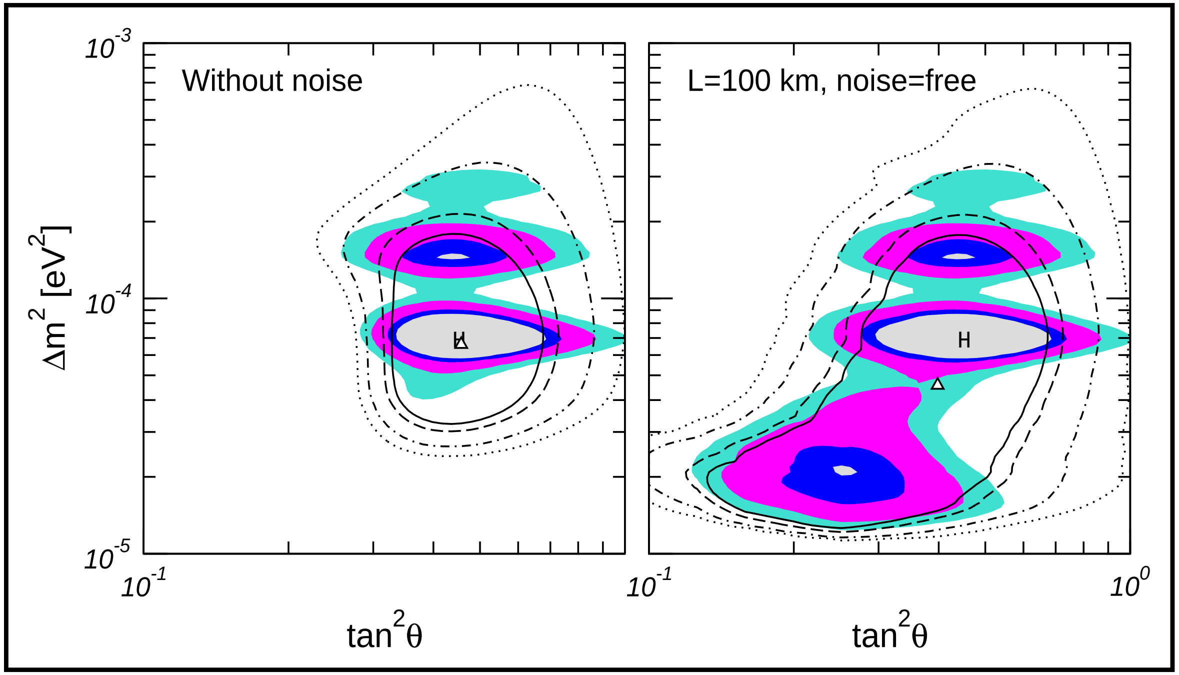
Balantekin et al 95

Nunokawa et al NPB472 (1996) 495

Burgess et al 97



substantial distortion



lower $\Delta m^2_{\rm SOL}$ possible

LSND

hints of neutrino conversions also from the detection of accelerator-produced neutrinos in the LSND experiment

4-nu models Peltoniemi, JV, NPB406, 409 (1993)

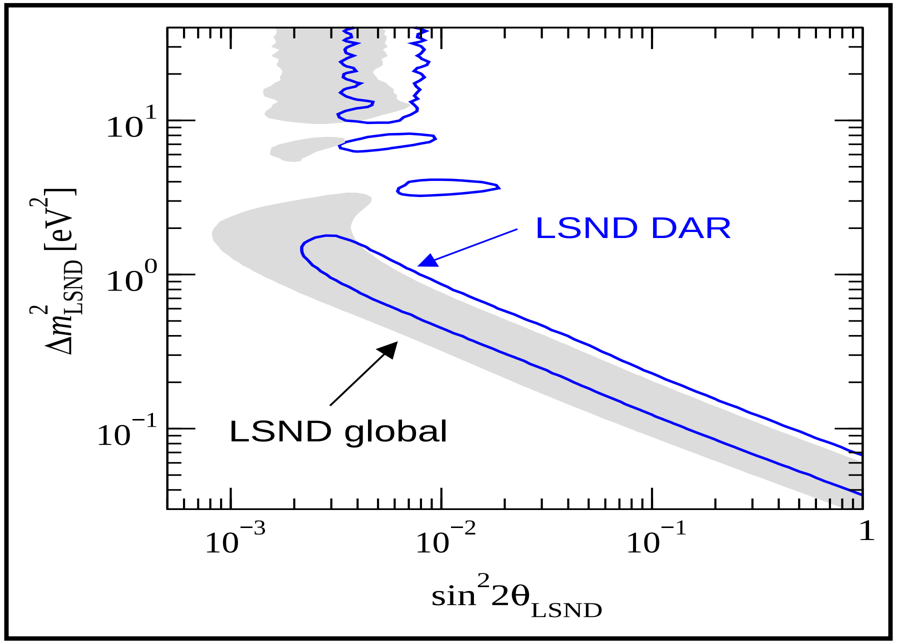
Peltoniemi, Tommasini and JV, PLB298 (1993) 383

Caldwell-Mohapatra PRD48 (1993) 325

barely possible at 3 σ

Maltoni et al NPB643 (2002) 321

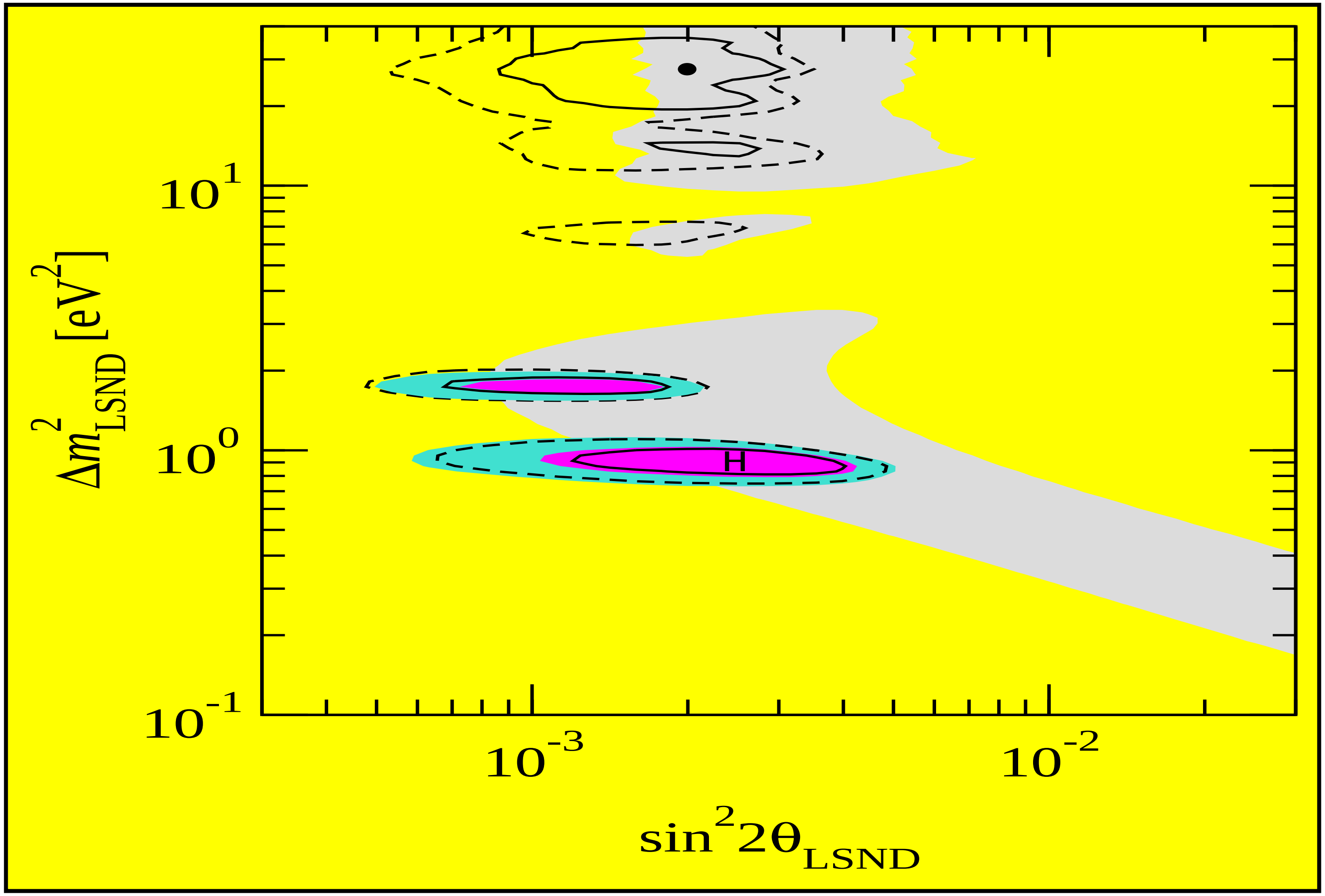
upd of PRD65 (2002) 093004



ATM

SOL

Cosmology closes in on LSND



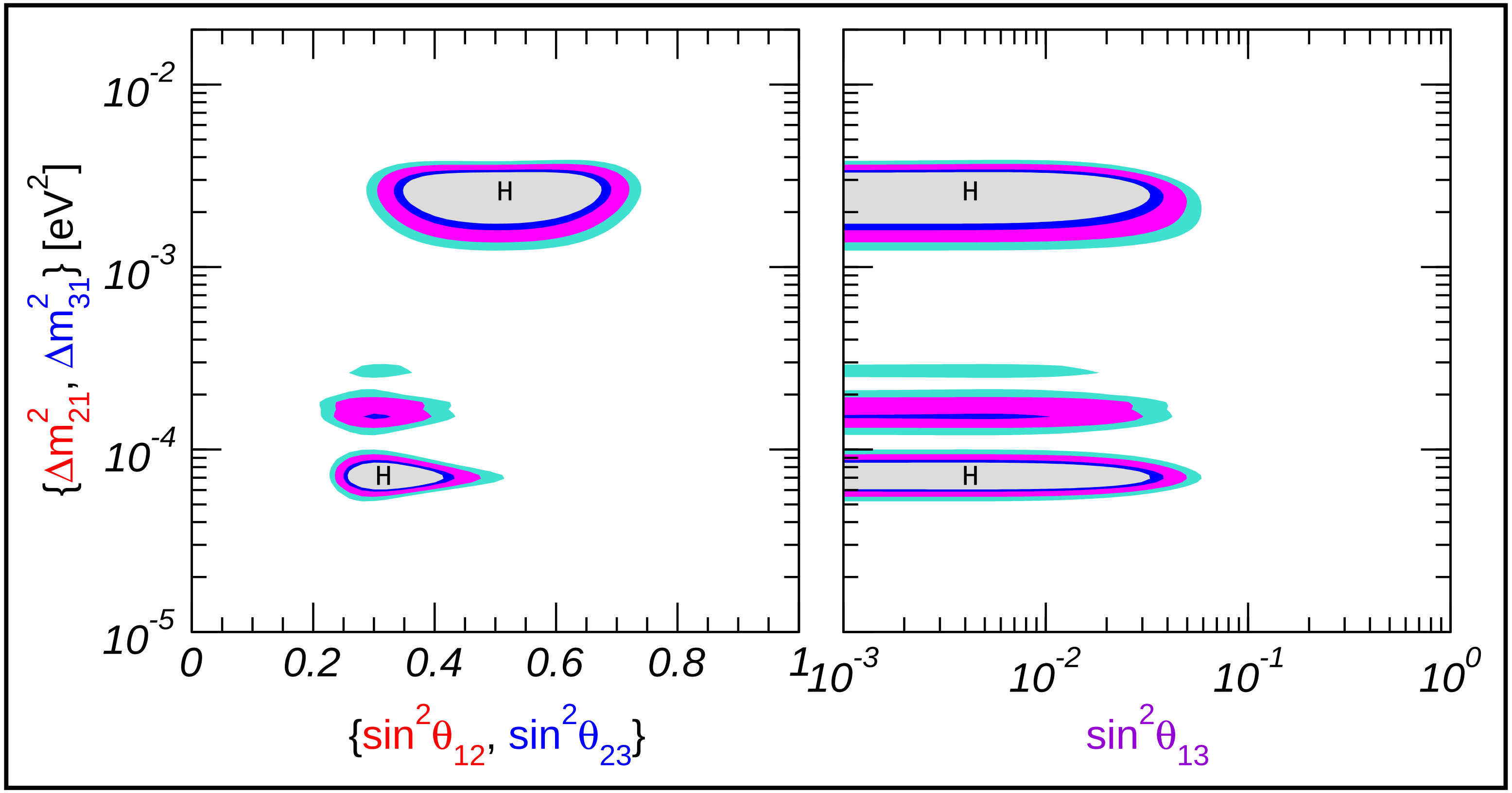
2df + WMAP + HST + SNIa

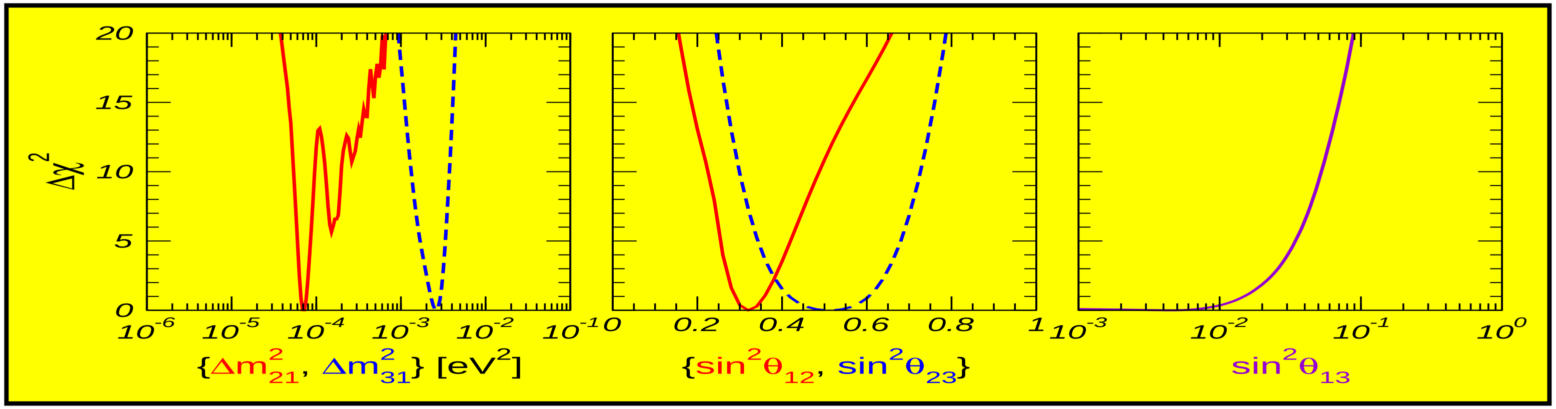
Schwetz et al hep-ph/0305312

Spergel et al, astro-ph/0302209; Hannestad, astro-ph/0303076; Elgaroy & Lahav, astro-ph/0303089

Three neutrino parameters in a nut shell

upg of **Maltoni et al, PRD67 (2003) 013011 & PRD 67 (2003) 093003**, upd of PRD63 (2001) 033005





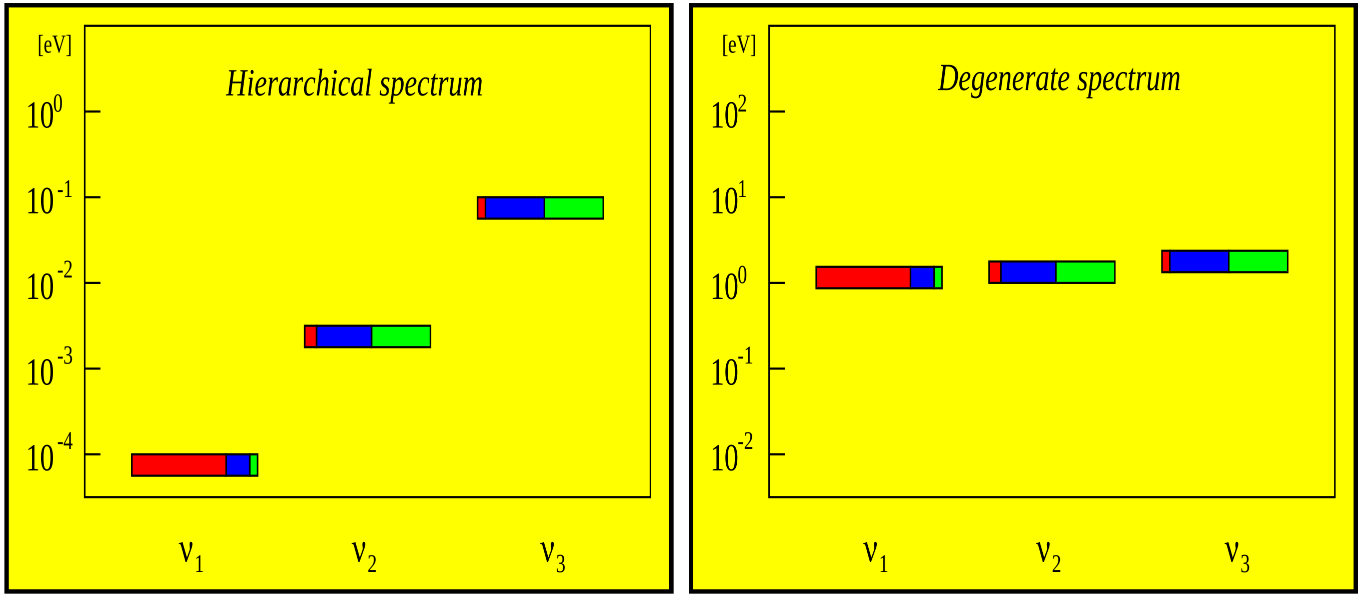
minimal set of basic parameters

- 3 angles θ_{ij} — 23=atm 12=sol 13=reac
  1 KM-like phase — oscillations — δ
  2 Majorana phases — $\beta\beta_{0\nu}$ — $\alpha\,,\beta$

Schechter and JV, PRD22 (1980) 2227, D23(1980) 1666

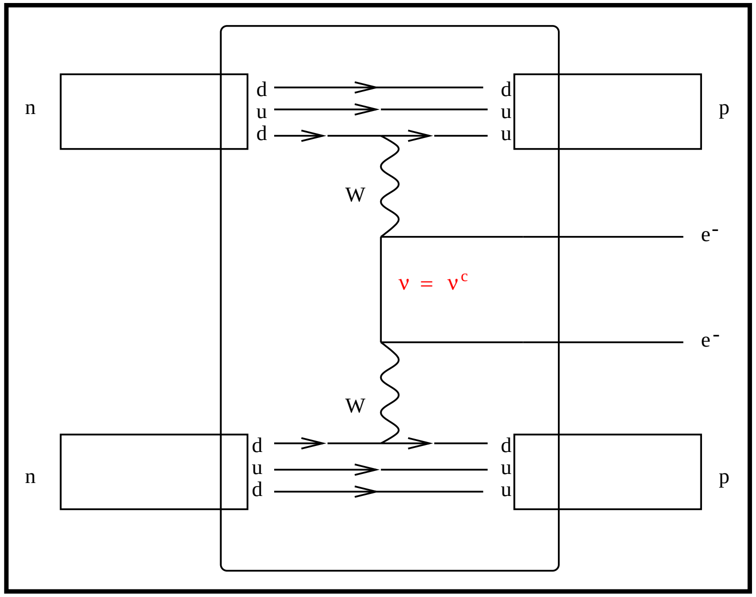
both appear in leptogenesis

- $\nu_e\ \nu_\mu\ \nu_\tau$



$\beta\beta_{0\nu}$ and the neutrino spectra (mass mechanism)

given that neutrinos are massive, one expects $\beta\beta_{0\nu}$ to occur with an amplitude governed by the average mass parameter



$$\langle m_\nu \rangle = \sum_j K_{ej}^2 m_j$$

parametrizing K as in

Schechter and JV, PRD22 (1980) 2227

$$\langle m_\nu \rangle = c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i\alpha} m_2 + s_{13}^2 e^{i\beta} m_3$$

- 3 masses: m_i
- 2 angles: θ_{12} and θ_{13}
- 2 CP violating phases: α, β

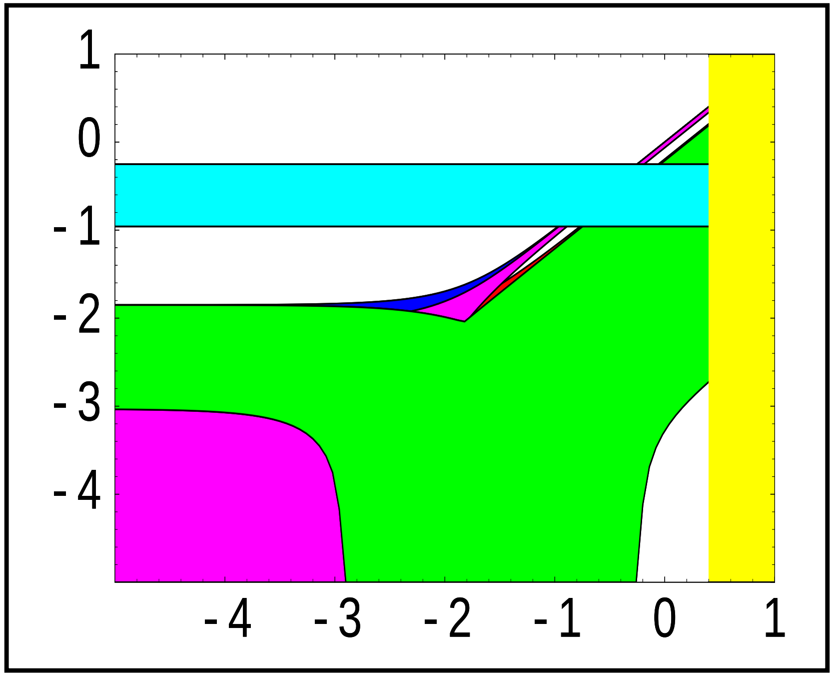
current laboratory tests of absolute neutrino mass

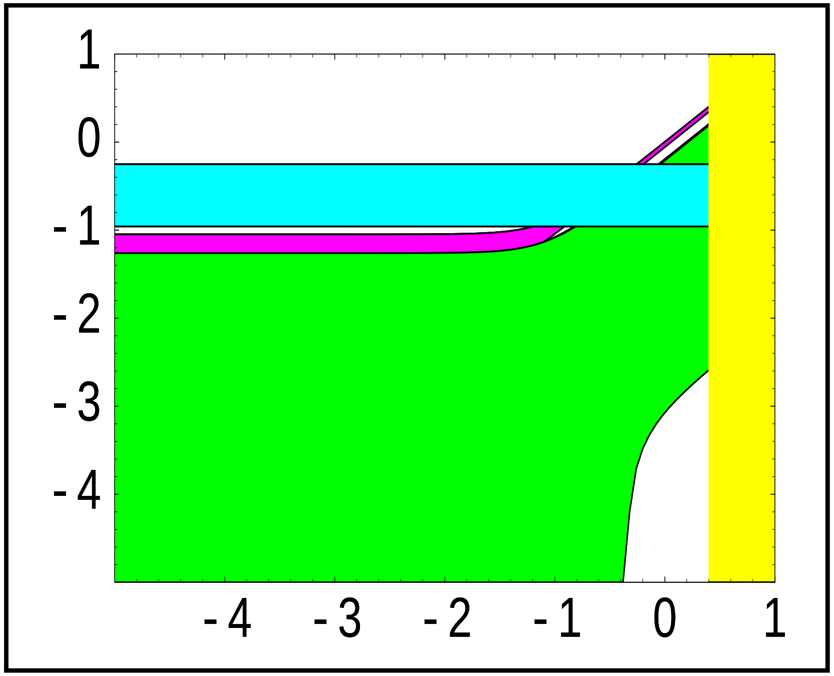
Current sol-atm, $\beta\beta_{0\nu}$ and Tritium sensitivities

thanks to Martin Hirsch

- Current neutrino oscillation data
- Upper limit for $\langle m_\nu \rangle \leq 0.3$ eV with factor ~ 2 uncertainty band
- Upper limit from Tritium experiments: $m_1 \leq 2.2$ eV

normal versus inverse hierarchy Log $\langle m_\nu \rangle$/eV vs Log m_1/eV



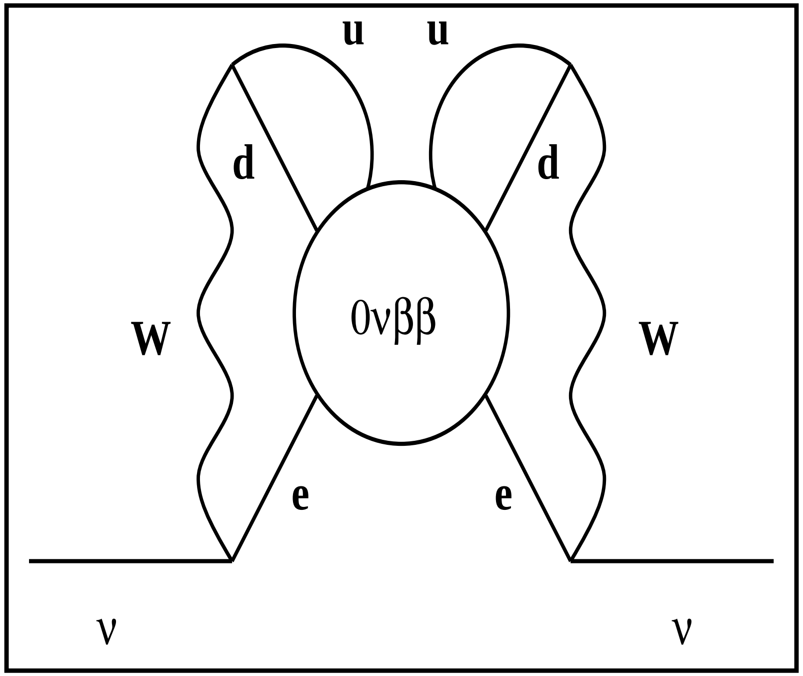


Relevance of $\beta\beta_{0\nu}$

gauge theories $\beta\beta_{0\nu} \leftrightarrow$ majorana mass

Schechter and JV, PRD **25** (1982) 2951

no such theorem for flavor violation!



Perversity of nature?

θ_{13} and Leptonic CP Violation

"Dirac" CPV suppressed, since δ disappears when any $\Delta_{ij} \to 0$

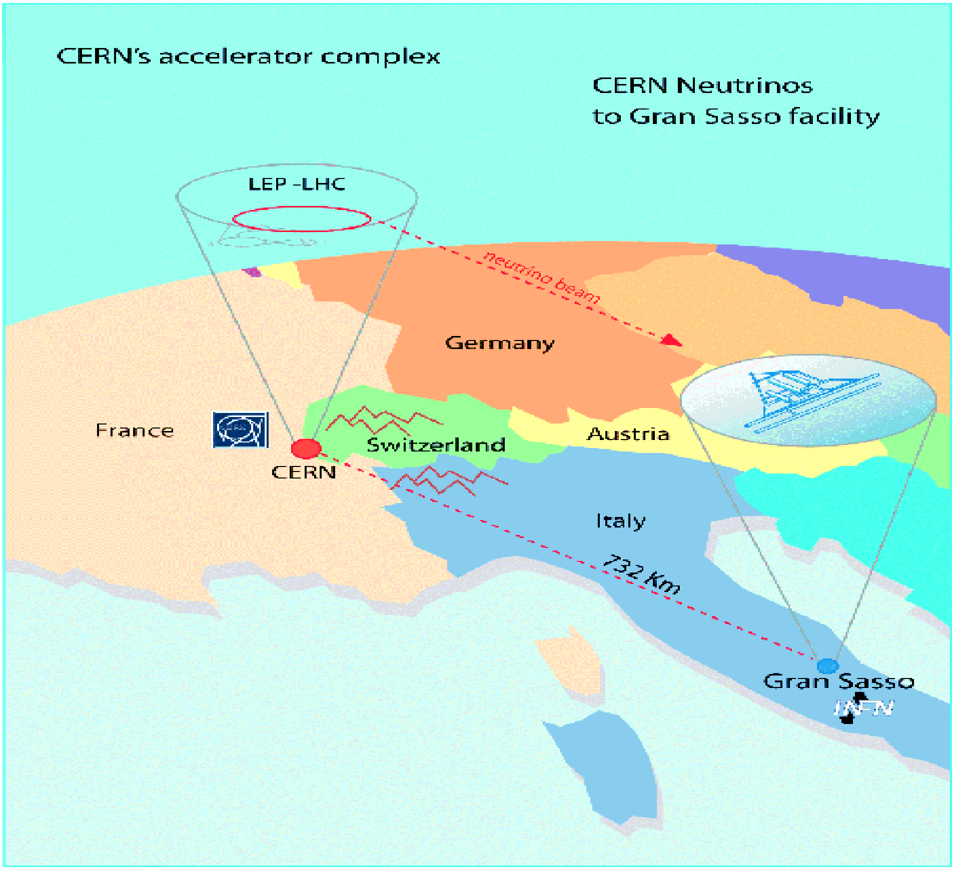
Schechter and JV, PRD **21** (1980) 309

Try harder

Neutrino Factories

will probe s_{13} and δ

Cervera et al, De Rujula, Gavela, Hernandez
Freund, Huber, Lindner, Albright et al, Barger et al...



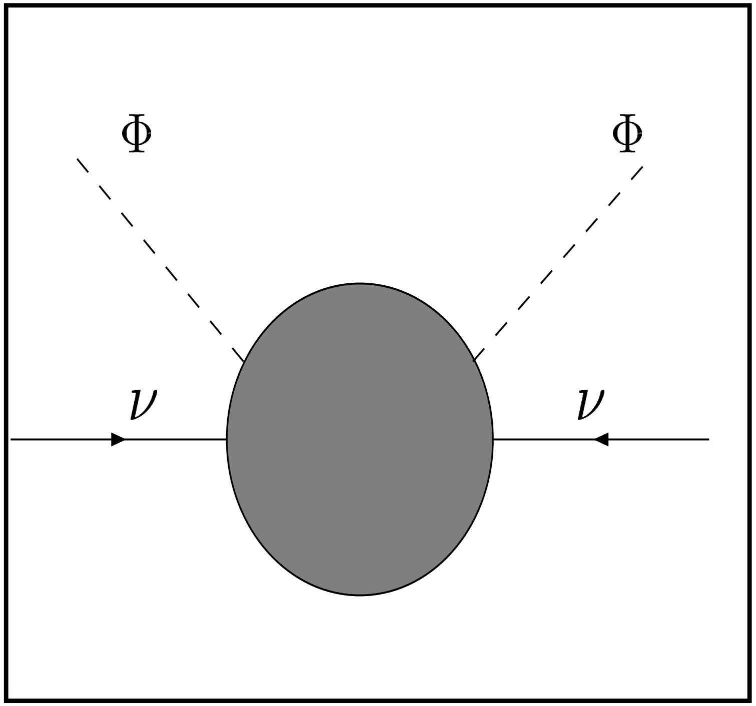
provided Non-Standard nu-Intercations (NSI) can be rejected ...

Huber, Schwetz & JV PRL88 (2002) 101804 & PRD66, 013006 (2002) •

Huber & JV PLB523 (2001) 151 •

Theory ideas

basic dim-5 operator ◉

- 

  from Gravity

  Weinberg ....

- from seesaw schemes

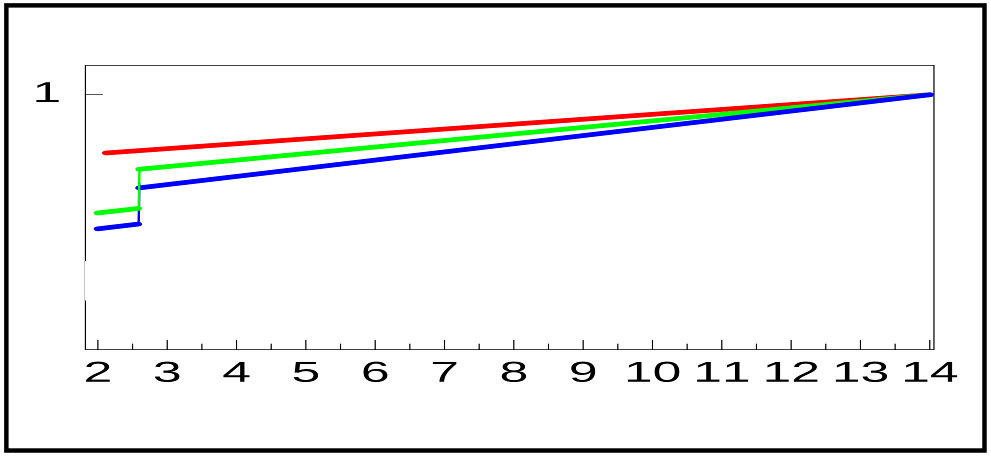
Gell-Mann, Ramond, Slansky; Yanagida;
Mohapatra, Senjanovic PRL44 (1980) 91
Schechter, JV PRD22 (1980) 2227; PRD25 (1982) 774

neutrino unification: large-scale seesaw

•

Babu, Ma and Valle, PLB552 (2003) 207

m_ν/eV vs. Log M_X/GeV



neutrino masses unify as they run up

Chankowski, Ioannisian, Pokorski and JV, PRL86 (2001) 3488

solar & atm splittings from RGE

common origin for neutrino and KM mixing

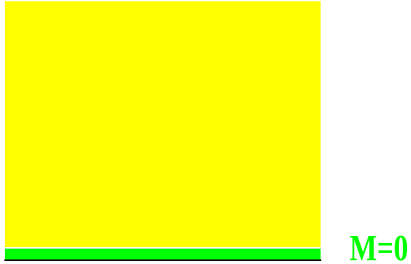
maximal θ_{23}; large θ_{12} & $\theta_{13} = 0$ or maximal CP violation see also Grimus & Lavoura

observable neutrino mass eg in cosmology, β and $\beta\beta_{0\nu}$ decays

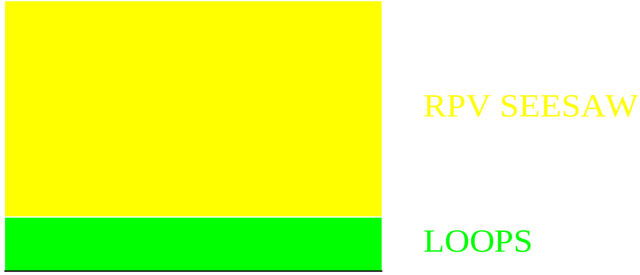
observable Lepton Flavor Violation $B(\tau \to \mu\gamma) \sim 10^{-6}$

bilinear R parity violation: weak-scale seesaw

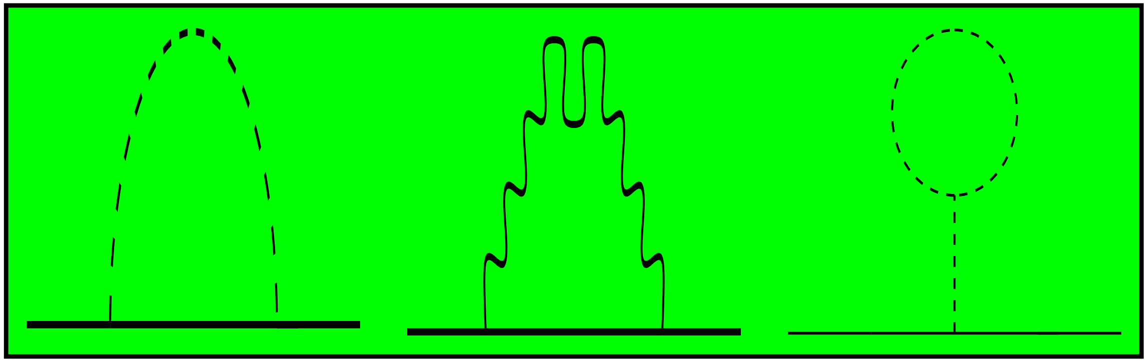
- Diaz, Hirsch, Porod, Romao and JV, PRD68 (2003) 013009 [hep-ph/0302021]; PRD62 (2000) 113008 [Err-ibid. D65 (2002) 119901]; PRD61 (2000) 071703



- weak-scale seesaw atm scale

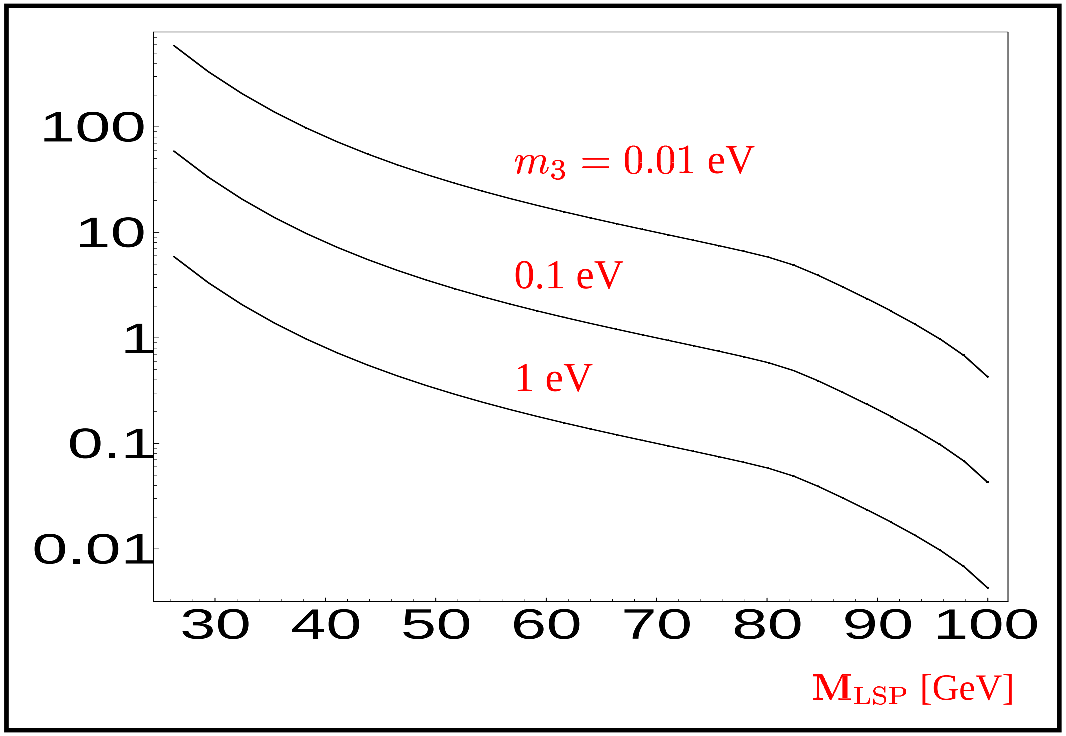


- radiative nu-masses solar scale



LSP decay length [cm]: BRPV

from Bartl et al NPB 600 (2001) 39



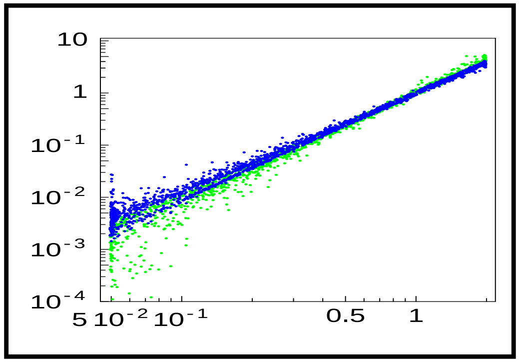
Mukhopadhyaya, Roy & Vissani; Chun & Lee; Choi et al; Datta et al

any charged SUSY particles can be the LSP

neutrino mixing angles in BRPV

$\tan^2_{23}(\Lambda_2/\Lambda_3)$ $\tan^2_{12}(\epsilon_1/\epsilon_2)$ $U^2_{e3}(\Lambda_1/\Lambda_3)$

- mixings in terms of RPV ratios, e,g, atm mixing

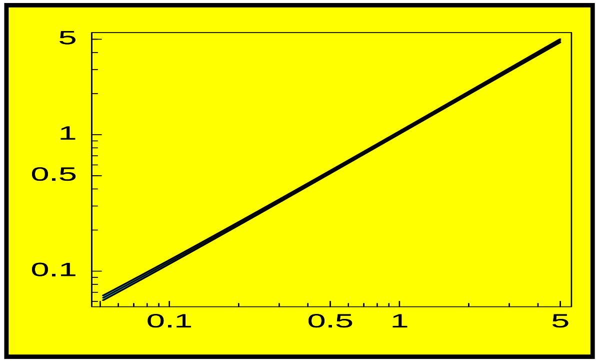


$\tan^2_{23}$ vs (Λ_2/Λ_3)

- LSP decay properties correlate with angles

neutralino

Porod et al PRD63 (2001) 115004



$\chi \to \mu q q / \chi \to \tau q q$ vs $\tan^2_{23}$

- stop decays
  slepton decays

Restrepo, Porod & Valle, PRD64 (2001) 055011

M. Hirsch et al, PRD66 (2002) 095006

No Road Map to Theory of Neutrino Mass

- top-bottom vs bottom-up
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...
- what is the scale ?
  - Planck scale: Strings?
  - GUT scale $E(6)$, $SO(10)$,...
  - Intermediate scale: P-Q, L-R ...
  - Weak $SU(3) \otimes SU(2) \otimes U(1)$ scale
- **no theory of flavour**
- are there sterile-nus?

http://alpha.ific.uv.es/˜valle/talks/talks.html