Neutrino Oscillations and New Physics

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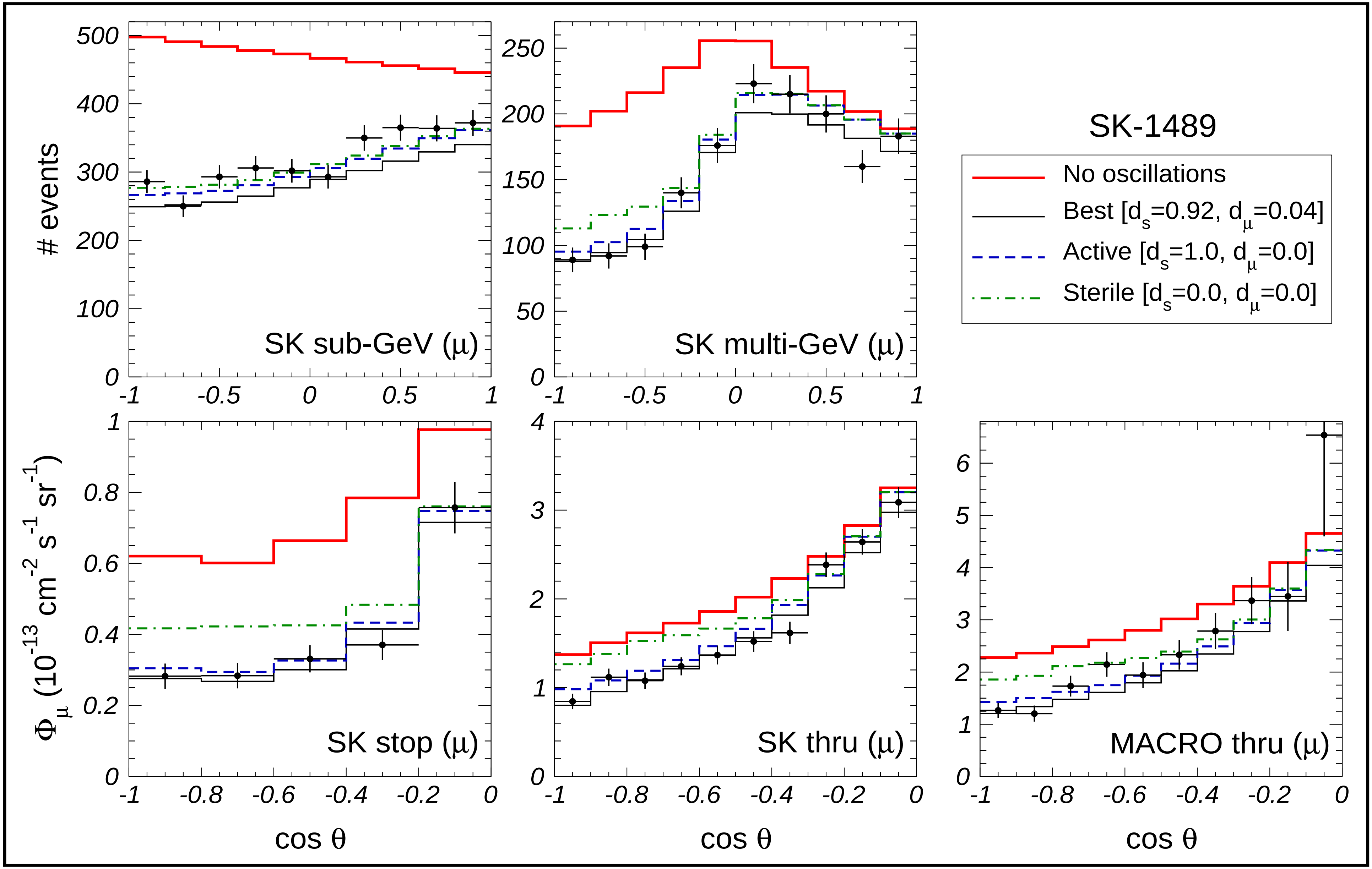
Based on hep-ph/0301061 and hep-ph/0307192
upd to include salt phase data from the SNO experiment

Maltoni, Tortola, Schwetz, JV, hep-ph/0309130, v2 (PRD, in press)

Atmospheric zenith distribution

Maltoni et al, PRD67 (2003) 013011



atmospheric neutrino parameters-1

- sterility rejection

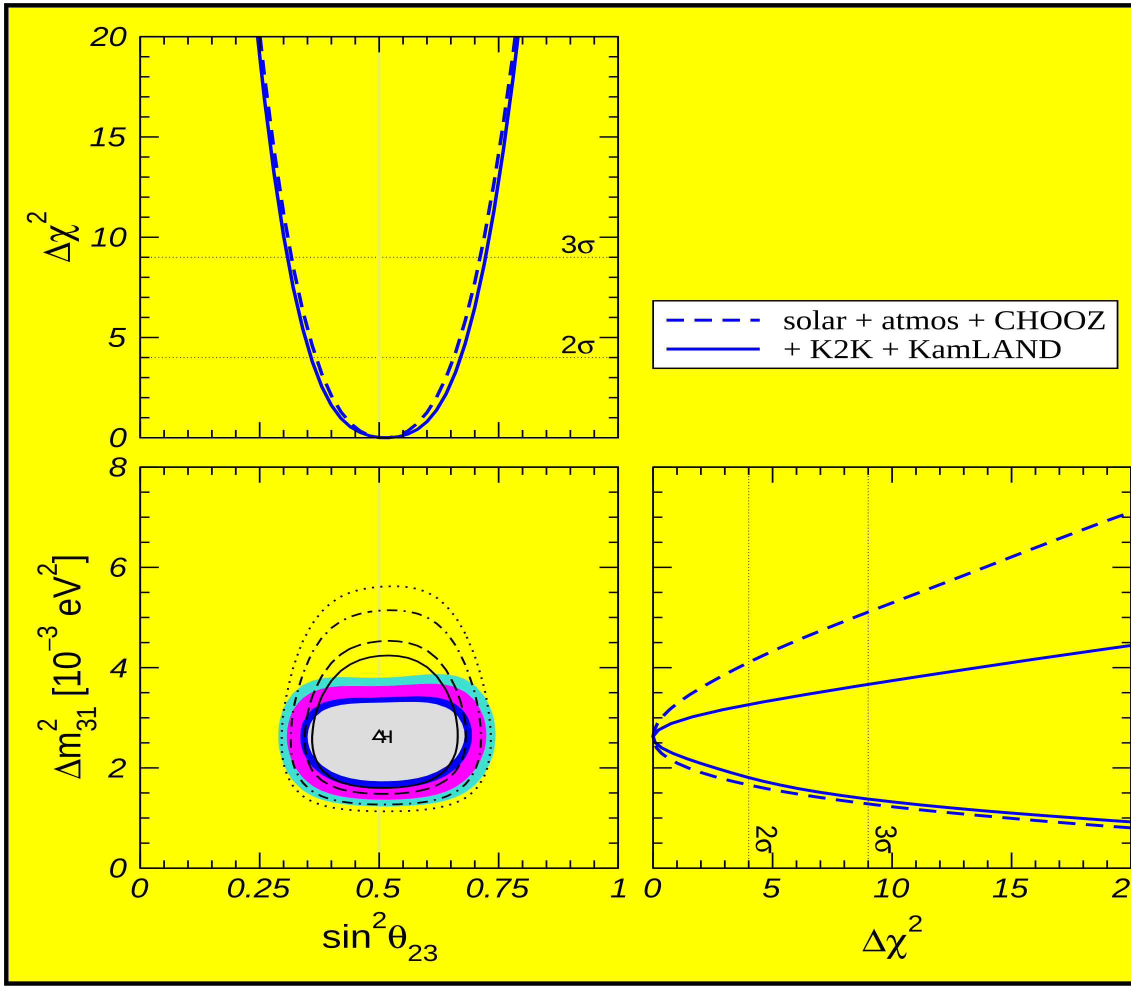
Maltoni et al, PRD, in press

upd of PRD67 (2003) 013011

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

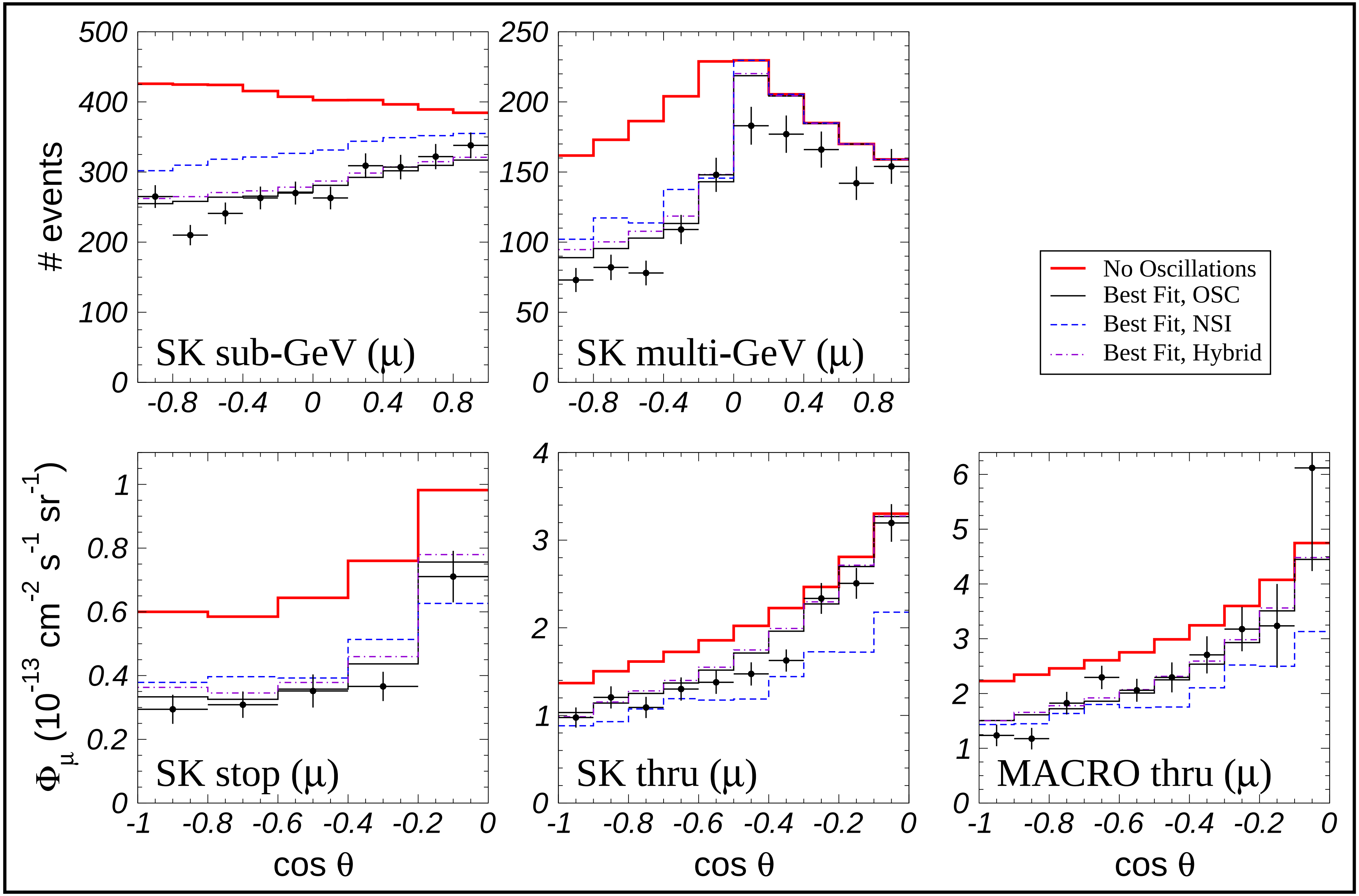
$\Delta m^2_{\rm ATM} = 2.6 \times 10^{-3}\ {\rm eV}^2$

K2K & $\Delta m^2_{\rm ATM}$ upper bound



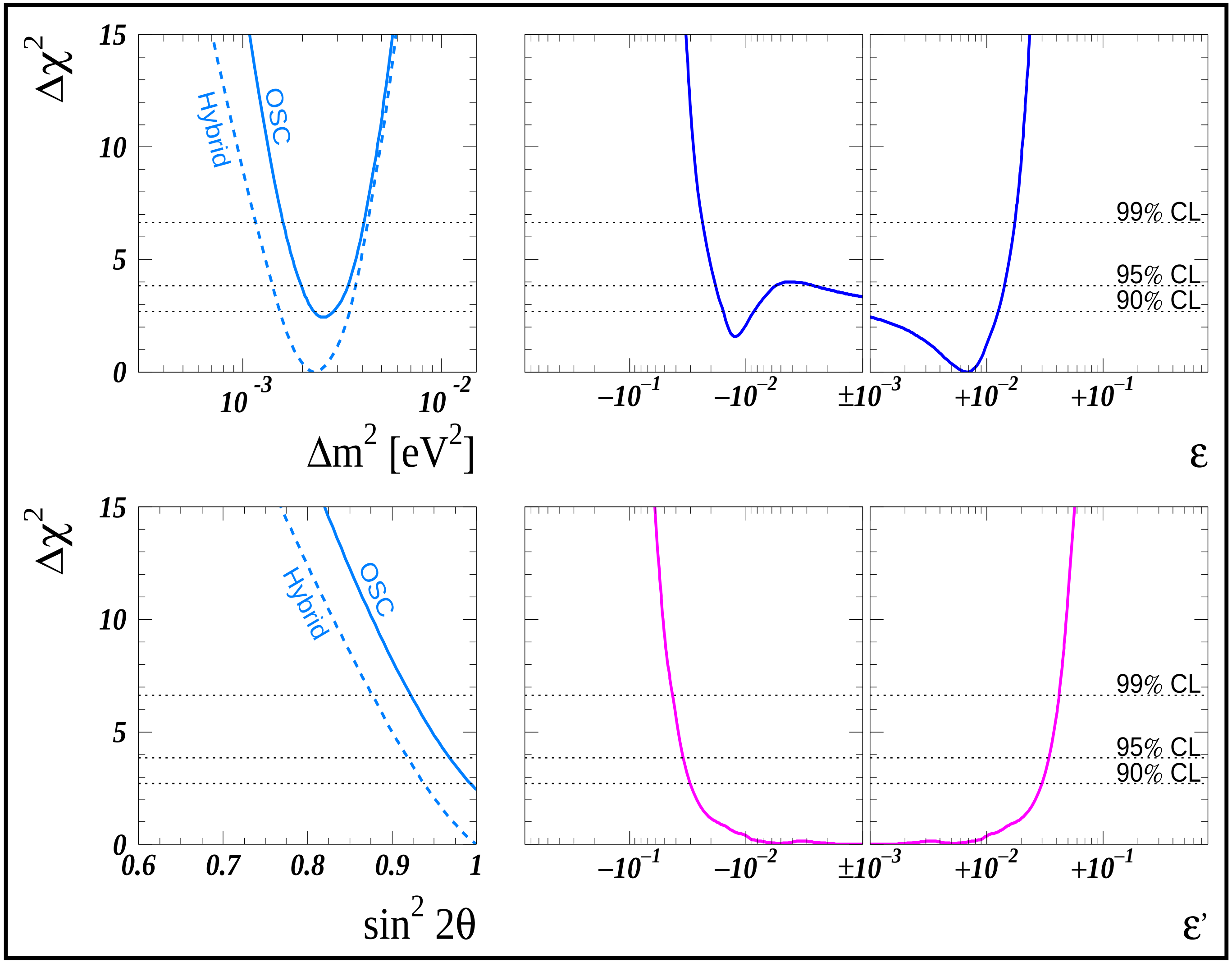
How robust are atmospheric oscillations?

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].

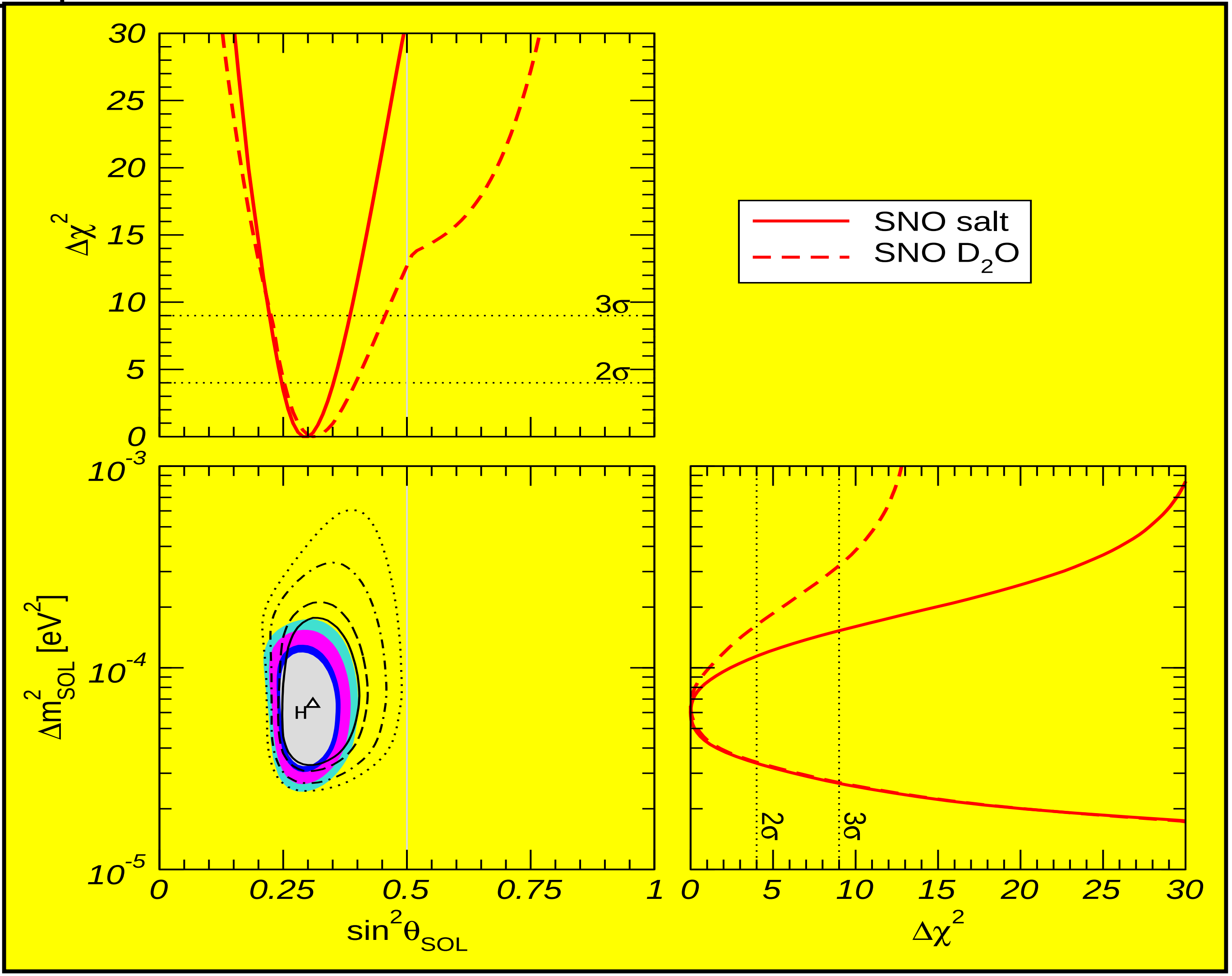


atm bounds on FC and NU nu-interactions

Solar neutrino parameters

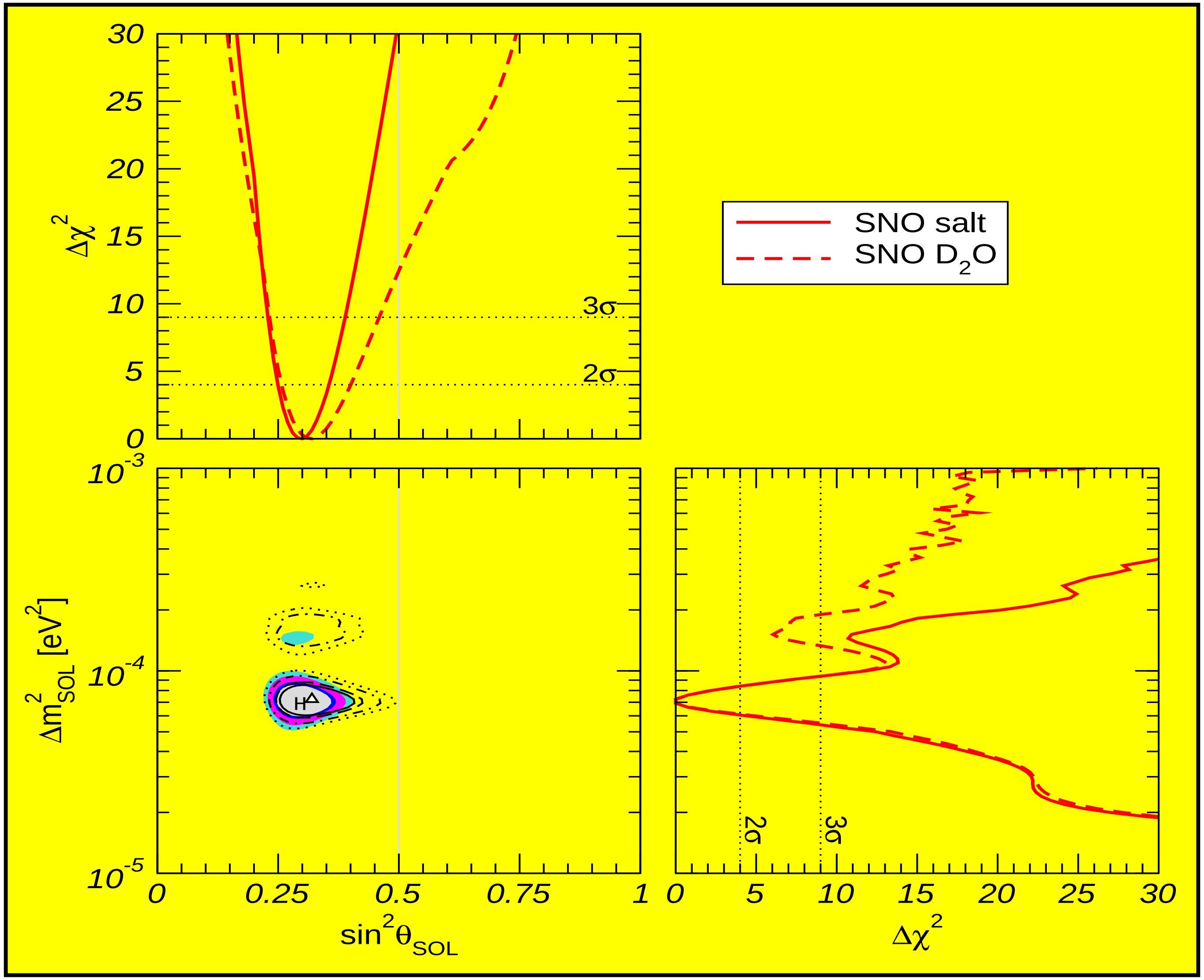
oscilllations happen inside the sun ! MSW

Maltoni et al, hep-ph/0309130 v2



Bandyopadhyay et al, Fogli et al, Balantekin et al

Solar + KamLAND results ● 3-nu



Maltoni et al, hep-ph/0309130 v2

upd of PRD67 (2003) 013011

and PRD67 (2003) 093003

enormous progress !

in contrast to atm, solar mixing is non-maximal

bi-maximal models rejecte

LMA-MSW status wrt SN1987A

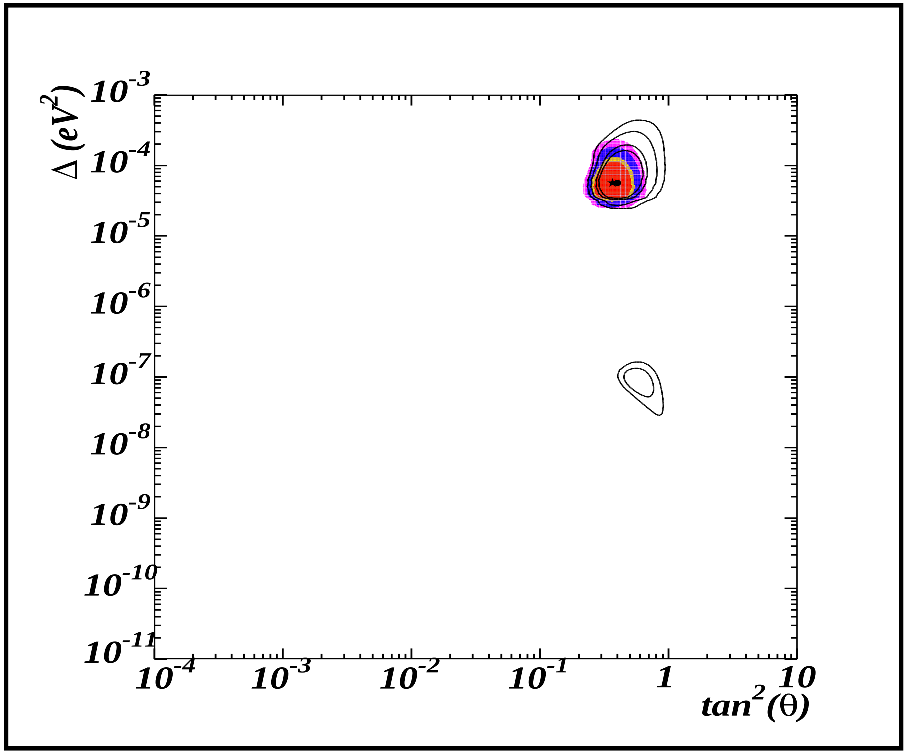
In 1987, a few neutrinos were detected from the nearby supernova 1987A galaxy about 170,000 light-years away

pre-KamLAND/pre-salt

LMA oscillations may strongly affect $\bar{\nu}_e$ SN-signal Smirnov, Spergel, Bahcall 94; Raffelt et al 96, Kachelriess et al JHEP 0101 (2001) 030, Lunardini & Smirnov

$E_{\bar{\nu}_e}$ =14 MeV,
$\mathrm{E_{bind}} = 3 \times 10^{53}$ erg
$\tau \equiv T_{\nu_h}/T_{\bar{\nu}_e}$=1.4
Keil, Raffelt & Janka, APJ590 (2003) 971

solar+SN1987A analysis



Kachelriess et al PRD65 (2002) 073016

LMA-MSW may remain best

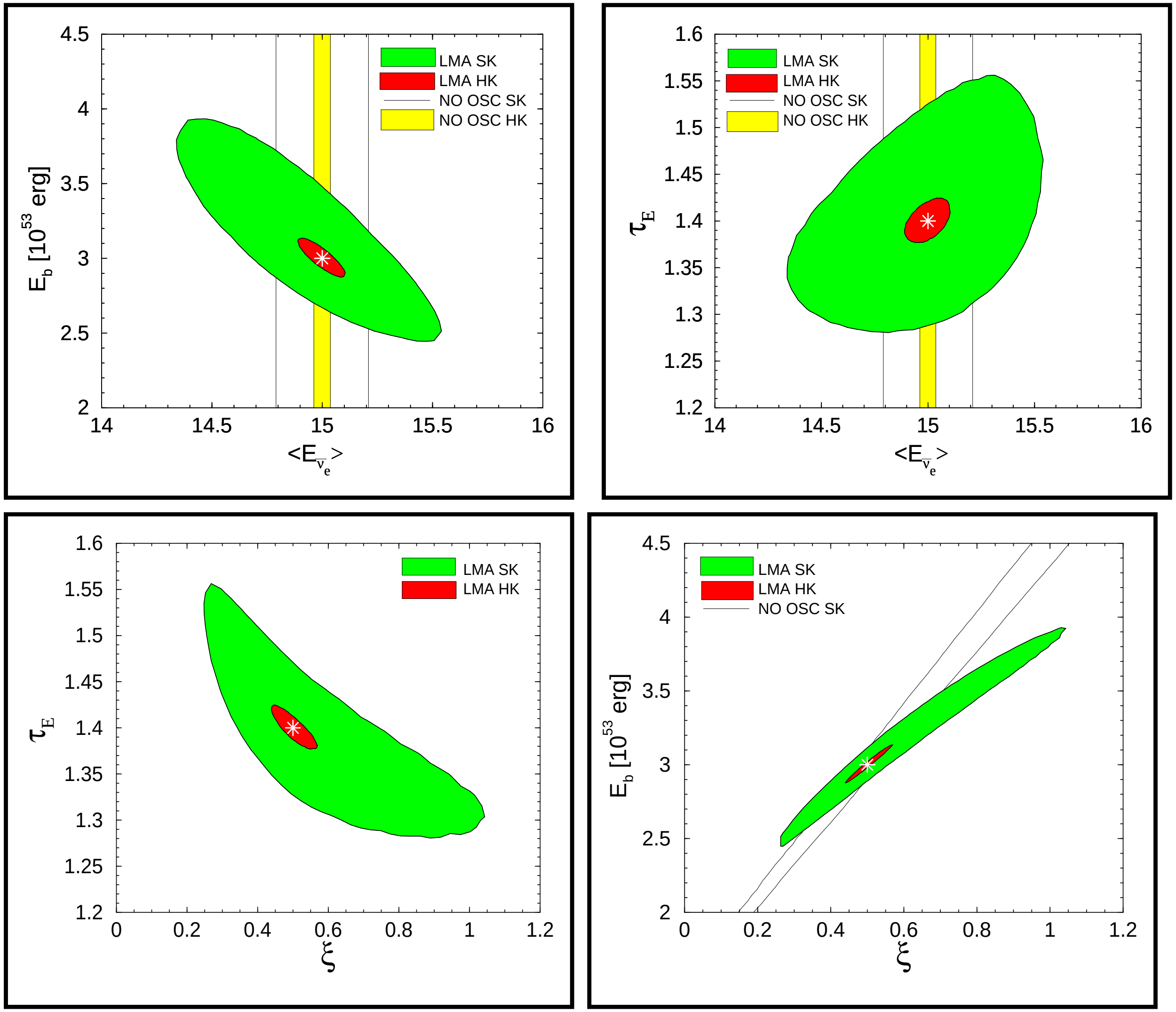
neutrinos as future Supernova probe

Minakata et al, PLB542 (2002) 239

The measurement of a large number of neutrinos from a future galactic supernova will give us important astro information

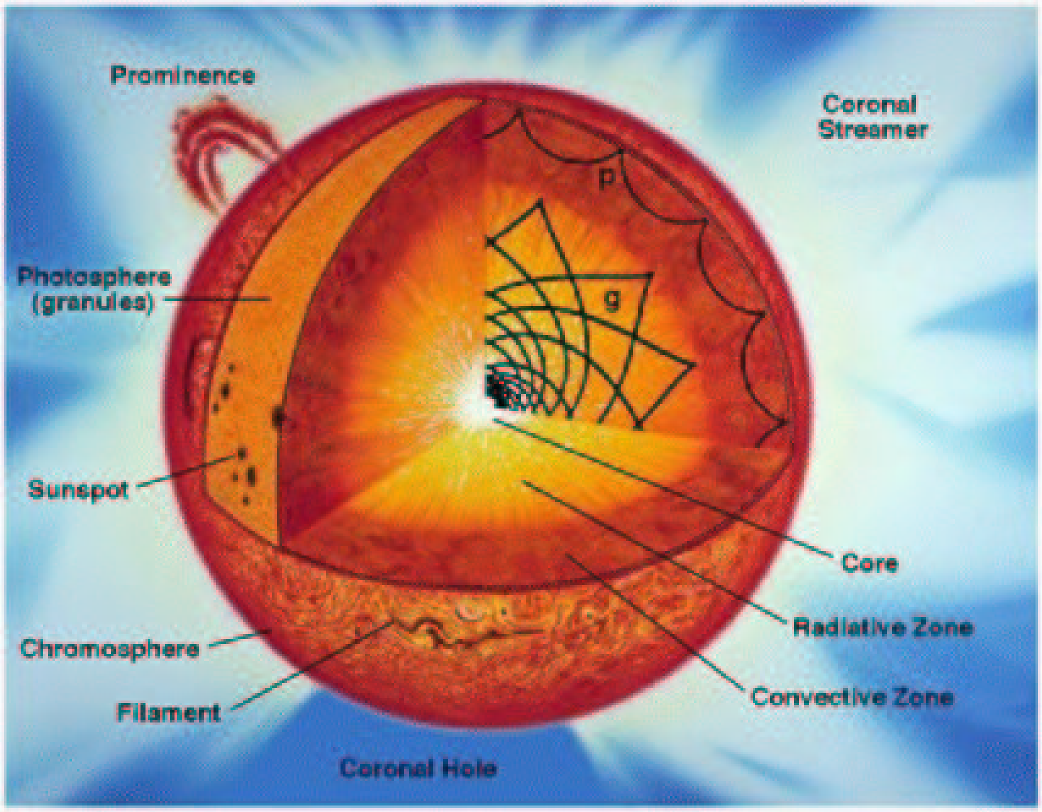
assume 10 kpc galactic SN, simulate data with given astro param

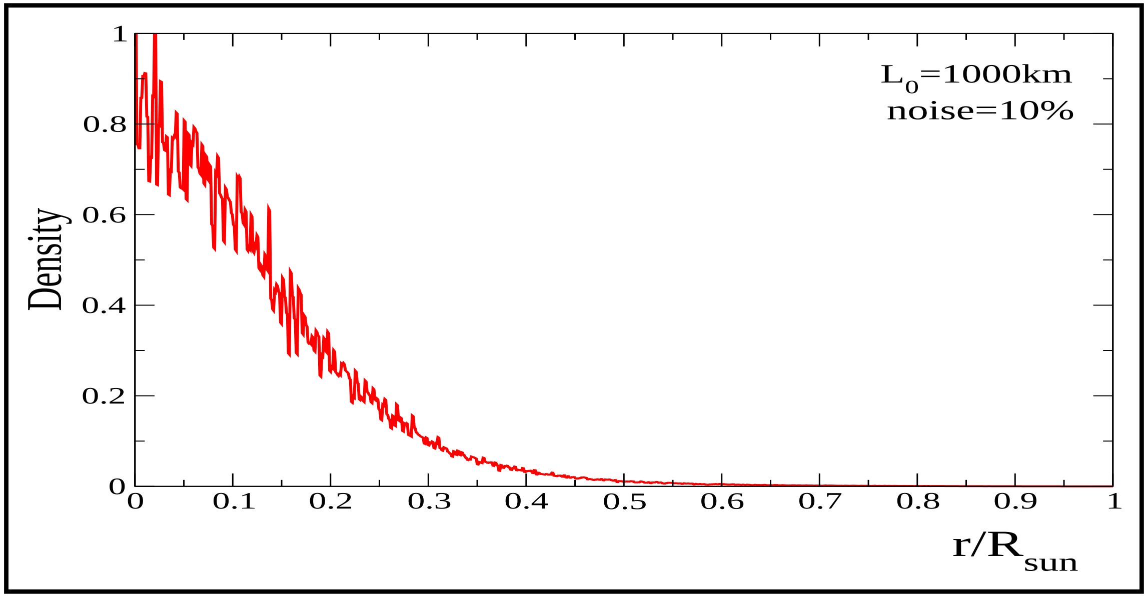
see also Barger, Marfatia & Wood



improved supernova parameter determination

do we understand the Sun?





Robustness of MSW plot

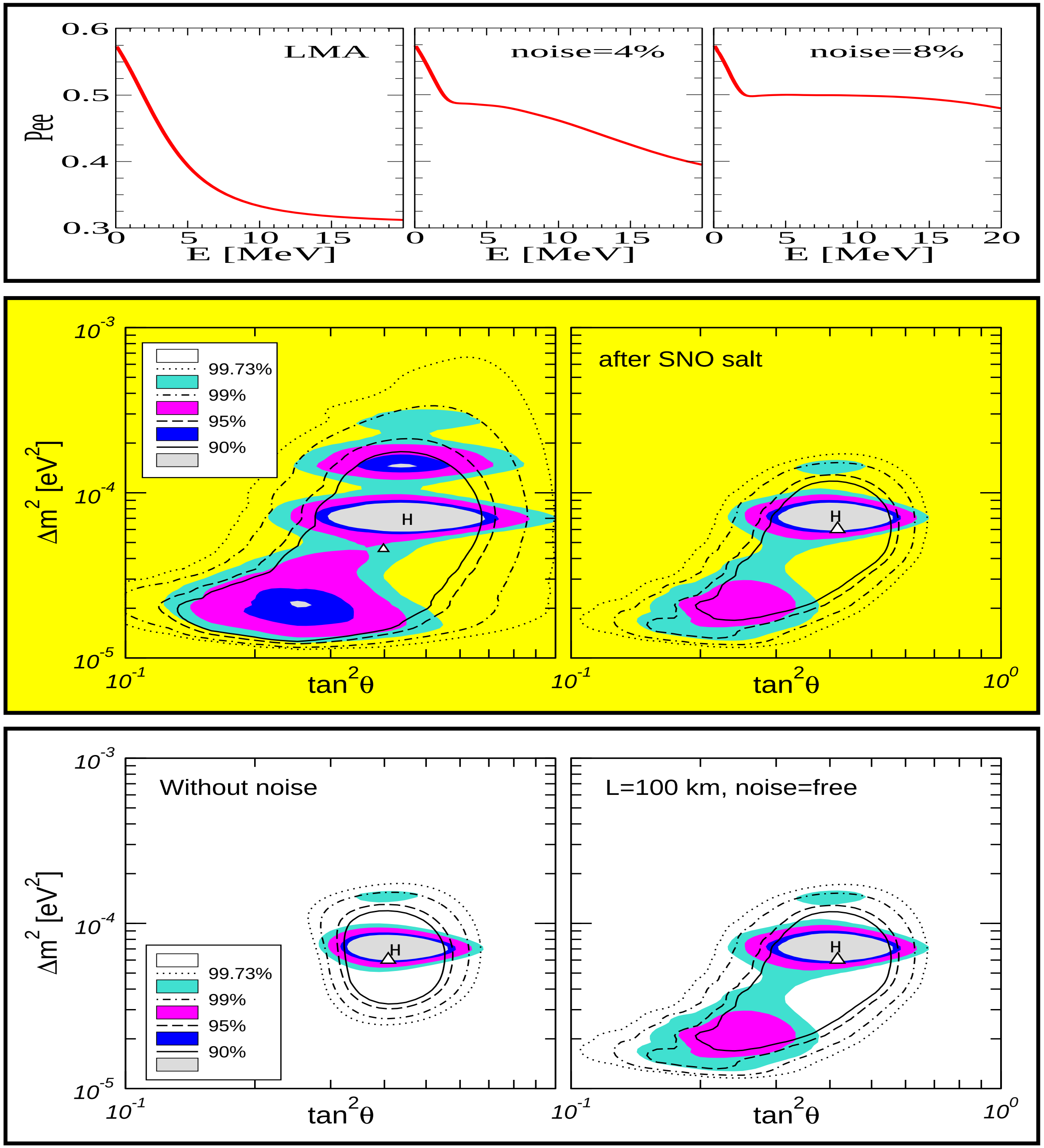
neutrino propagation strongly affected by density noise

Balantekin et al 95

Nunokawa et al NPB472 (1996) 495

Burgess et al 97

Burgess et al, Ap.J.588:L65 ,2003



despite substantial distortion

robust determination

Burgess et al, hep-ph 0310366

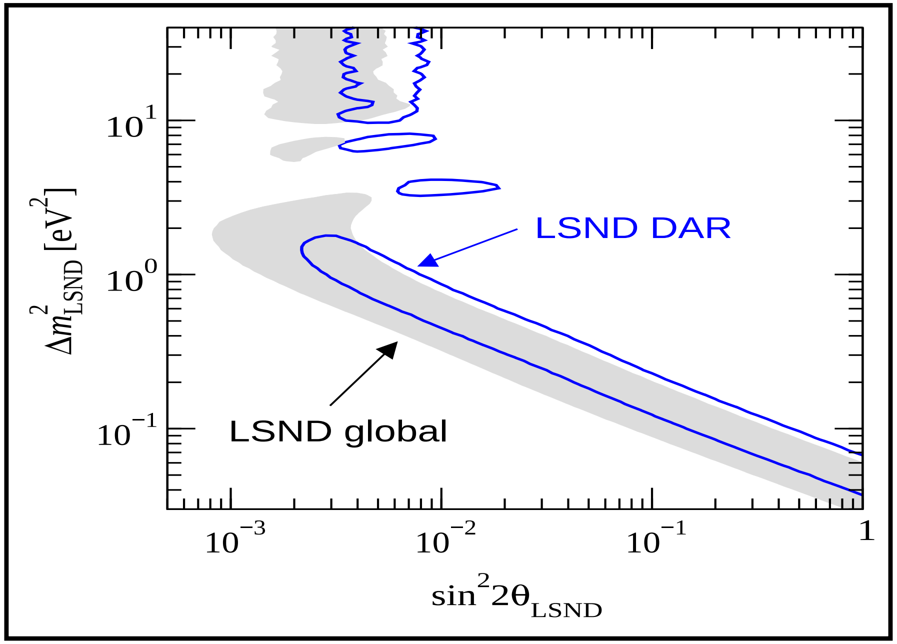
LSND

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 3.2 σ if 3+1

Maltoni et al NPB643 (2002) 321

upd of PRD65 (2002) 093004

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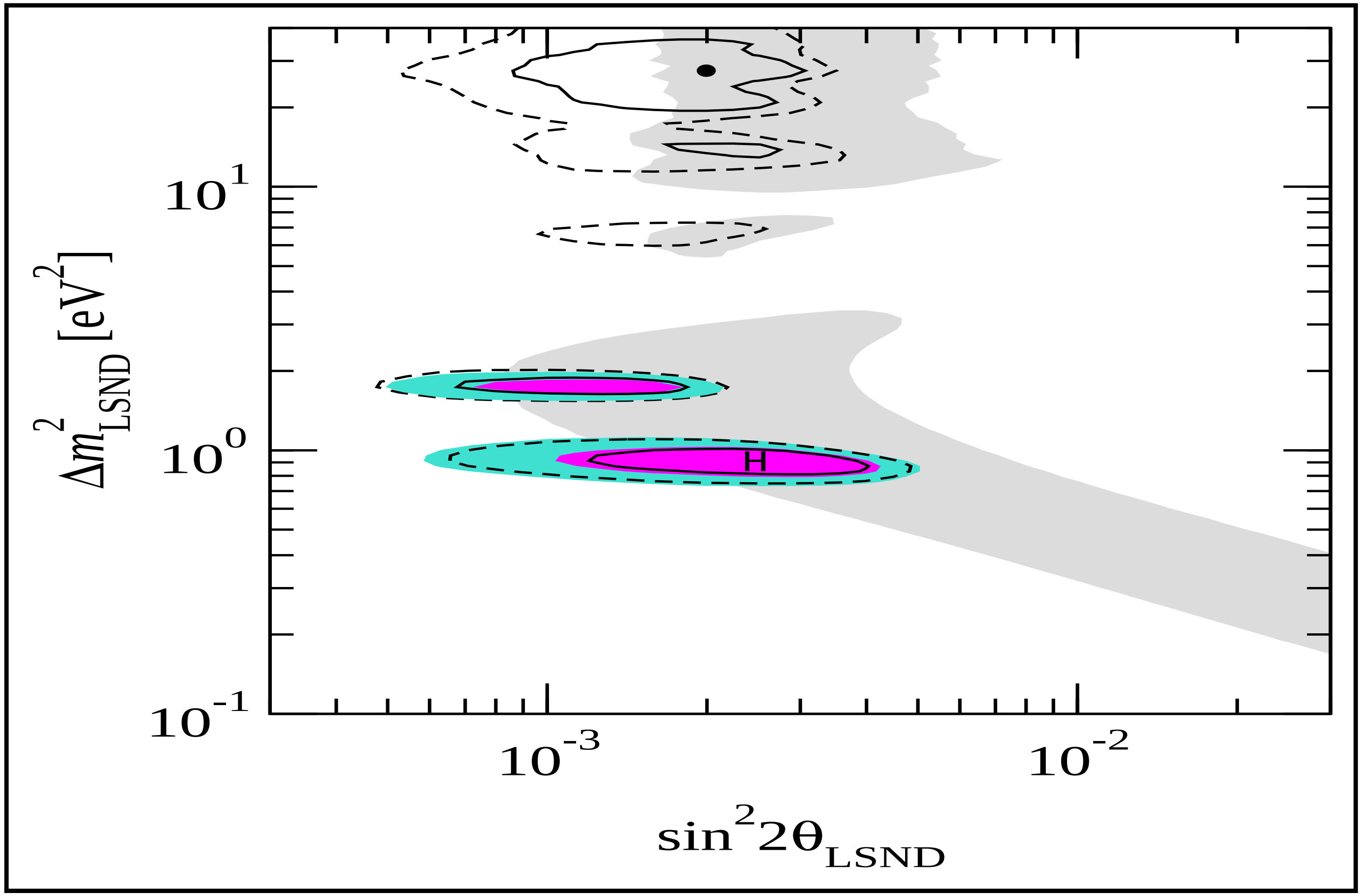
Cosmology closes in on LSND

3+1 scheme still OK at 3sigma, higher masses excluded



2df + WMAP + HST + SNIa

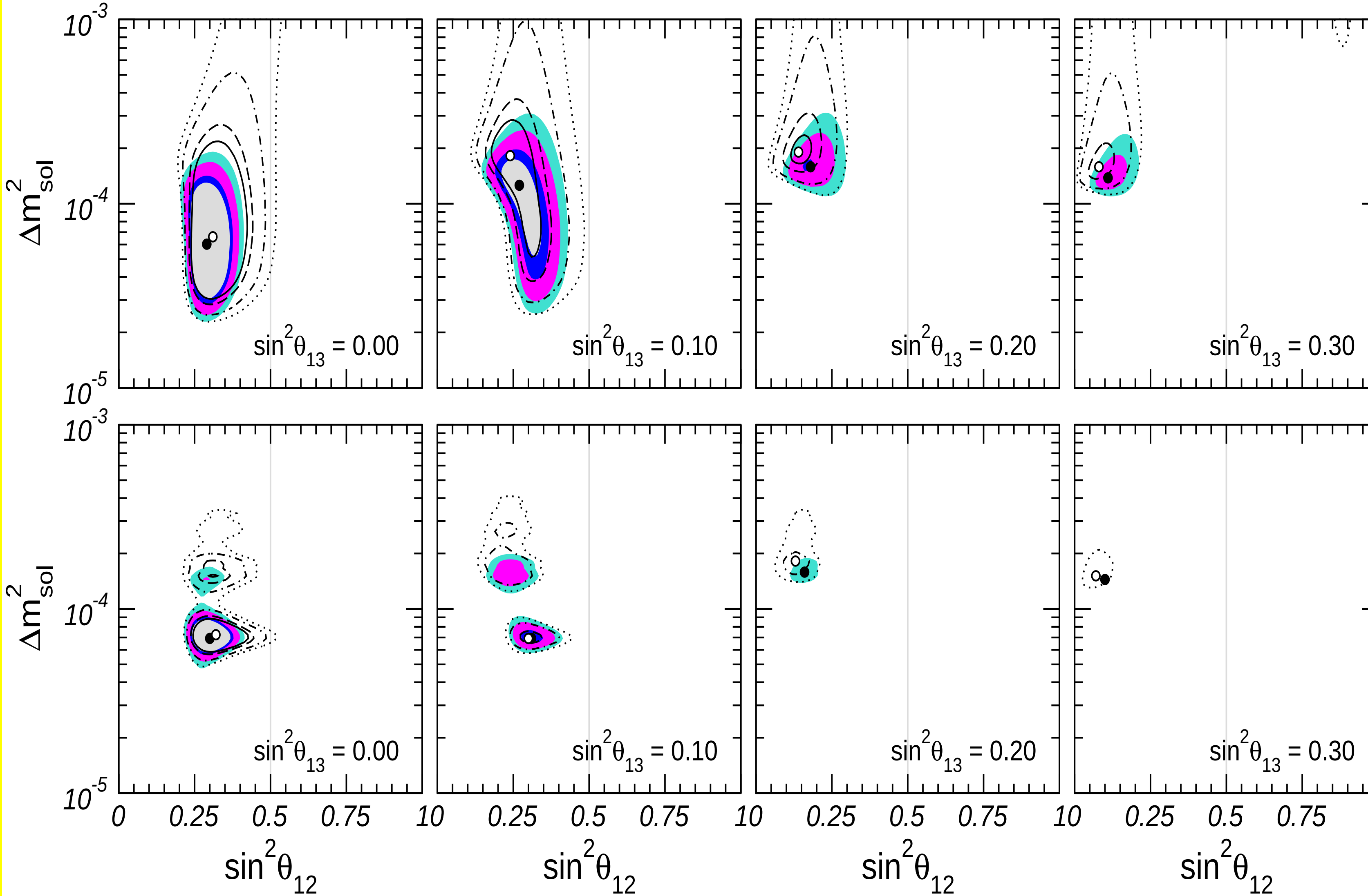
Schwetz et al hep-ph/0305312

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

Crotty, Lesgourgues & Pastor PRD67 (2003) 123005

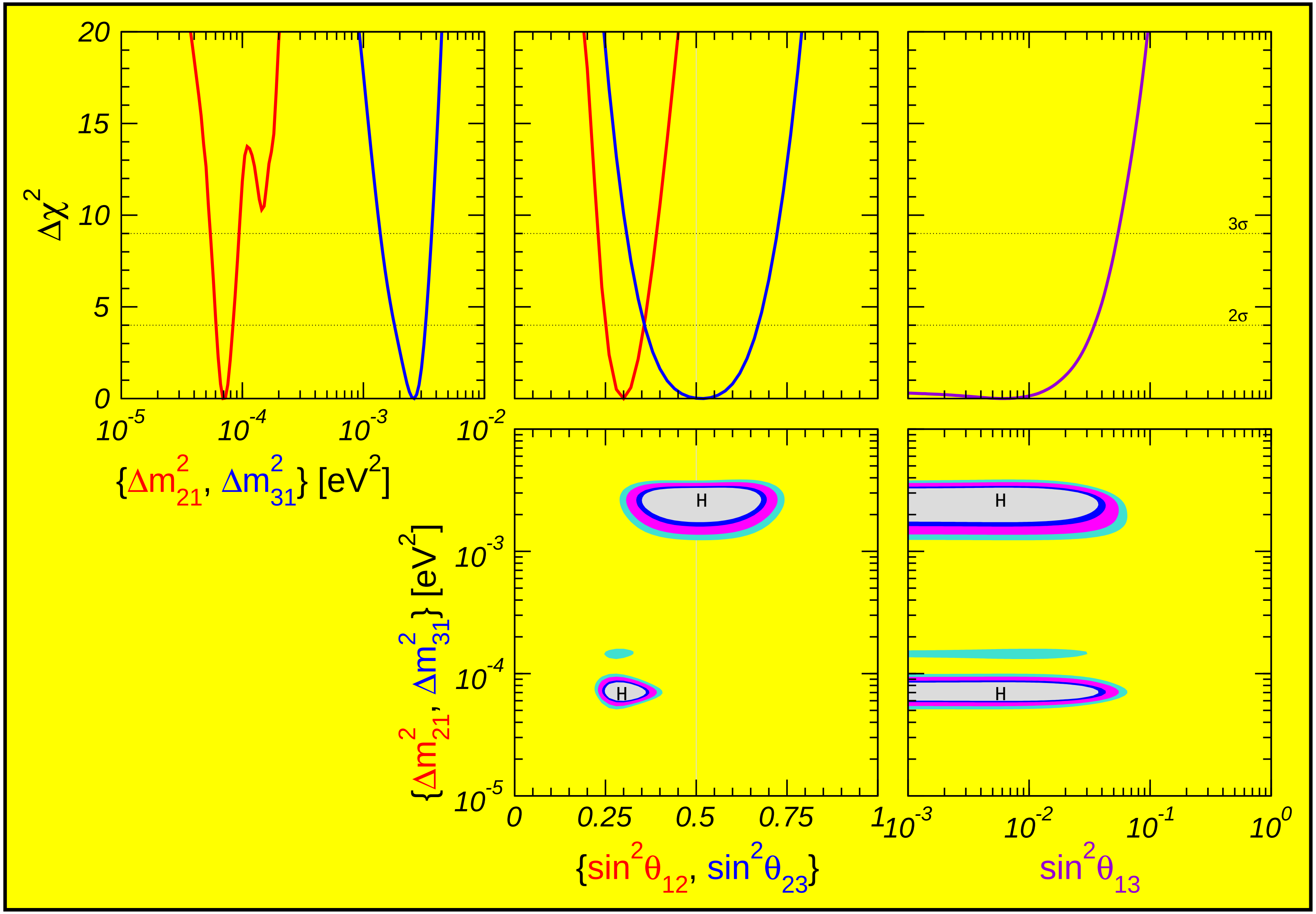
3-nu regions: before and after salt

- Maltoni et al, hep-ph/0309130 v2 without KamLAND (top), with KamLAND (bottom)



3-nu parameters

- Maltoni et al, hep-ph/0309130 v2, upd of PRD63 (2001) 033005



3-nu Oscillation Parameters

hep-ph/0309130 v2 PRD

parameter	best fit	2σ	3σ	5σ
Δm^2_{21} [10^{-5}eV^2]	6.9	6.0–8.4	5.4–9.5	2.1–28
Δm^2_{31} [10^{-3}eV^2]	2.6	1.8–3.3	1.4–3.7	0.77–4.8
$\sin^2\theta_{12}$	0.30	0.25–0.36	0.23–0.39	0.17–0.48
$\sin^2\theta_{23}$	0.52	0.36–0.67	0.31–0.72	0.22–0.81
$\sin^2\theta_{13}$	0.006	≤ 0.035	≤ 0.054	≤ 0.11

Table I: Best-fit values, 2σ, 3σ and 5σ intervals (1 d.o.f.) for the three-flavour neutrino oscillation parameters from global data including solar, atmospheric, reactor (KamLAND and CHOOZ) and accelerator (K2K) experiments.

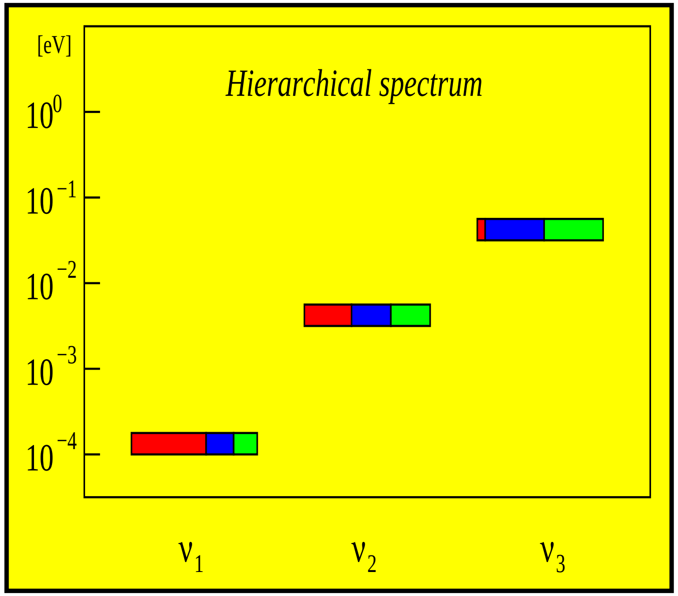
minimal set of basic parameters

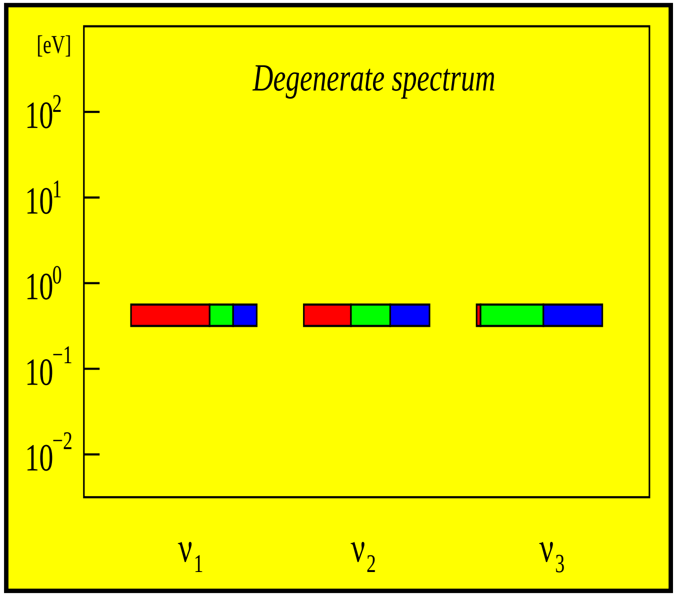
- 3 angles θ_{ij} 23=atm 12=sol 13=reac

  1 KM-like phase oscillations δ

  2 Majorana phases $\beta\beta_{0\nu}$ α , β

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

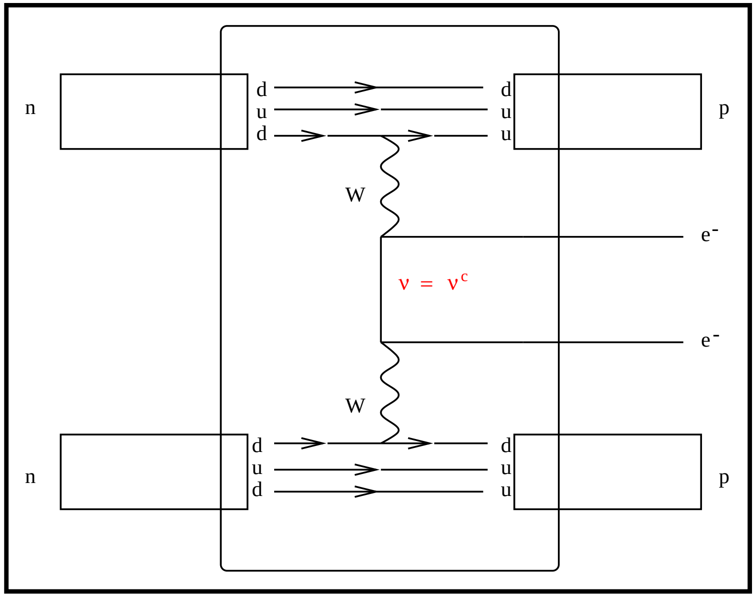




- ν_e ν_μ ν_τ

0-nu double beta decay and the neutrino spectra

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



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

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

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

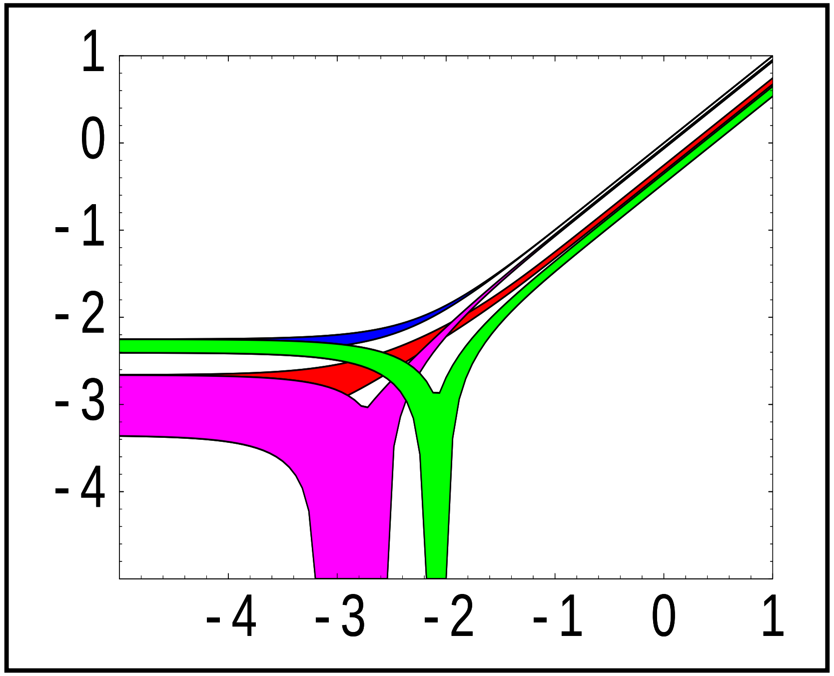
current laboratory tests of absolute neutrino mass

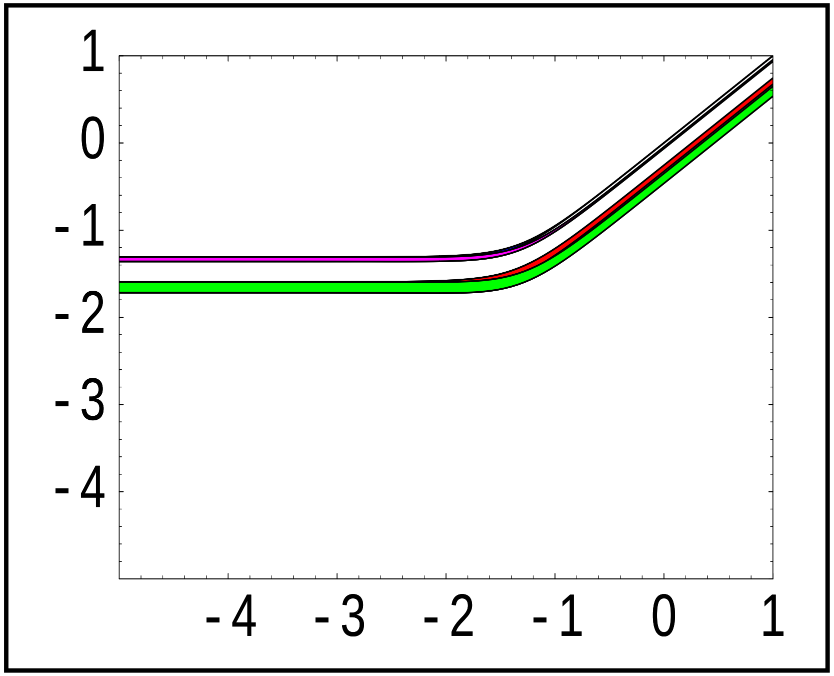
Current sol-atm, $\beta\beta_{0\nu}$ and Tritium sensitivities

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



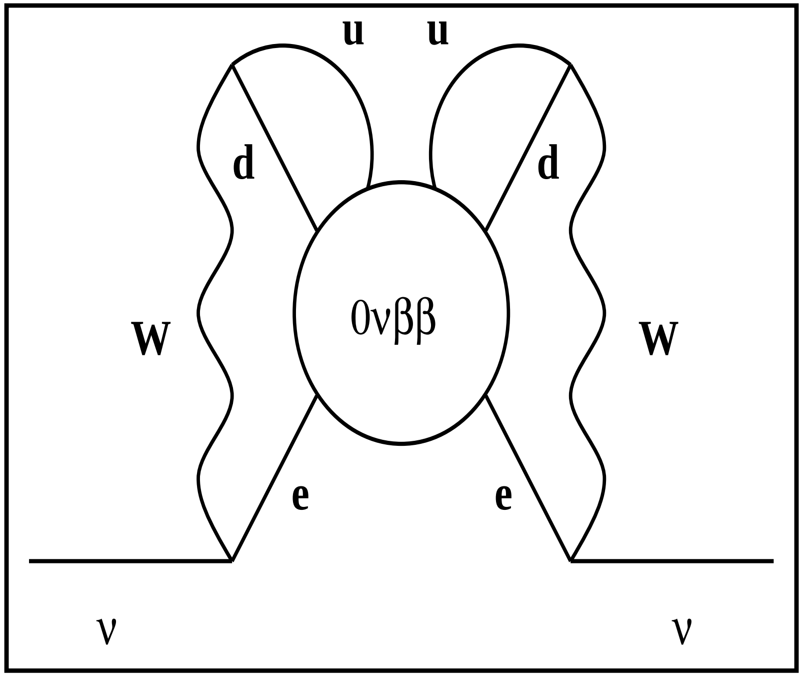


Relevance of 0-nu double beta decay

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

In any gauge theory of the weak interaction a non-zero $\beta\beta_{0\nu}$ rate implies at least one neutrino is a Majorana particle

Schechter and JV, PRD25 (1982) 2951



no such theorem for flavor violation!

probing 3-nu oscillation effects

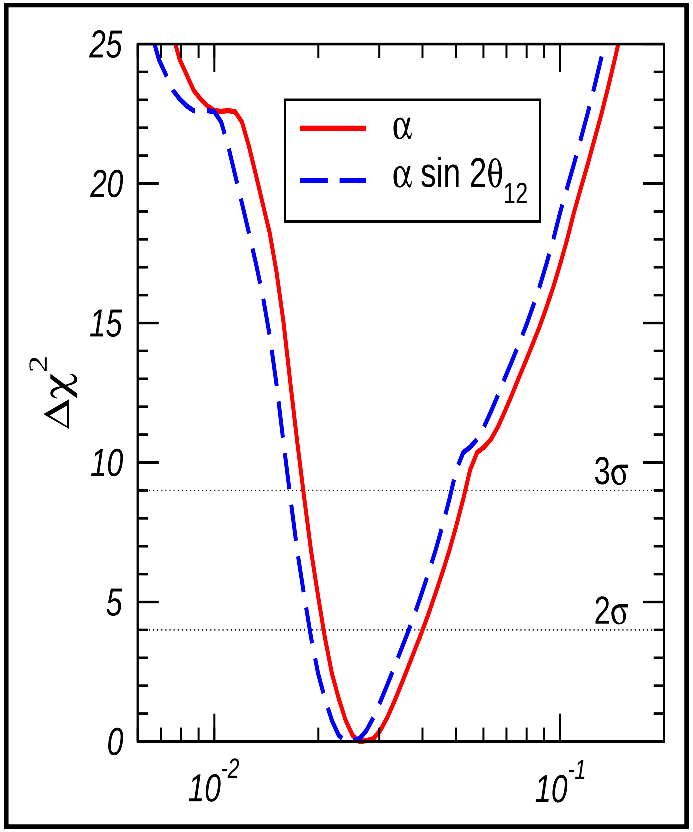
Leptonic CP Violation

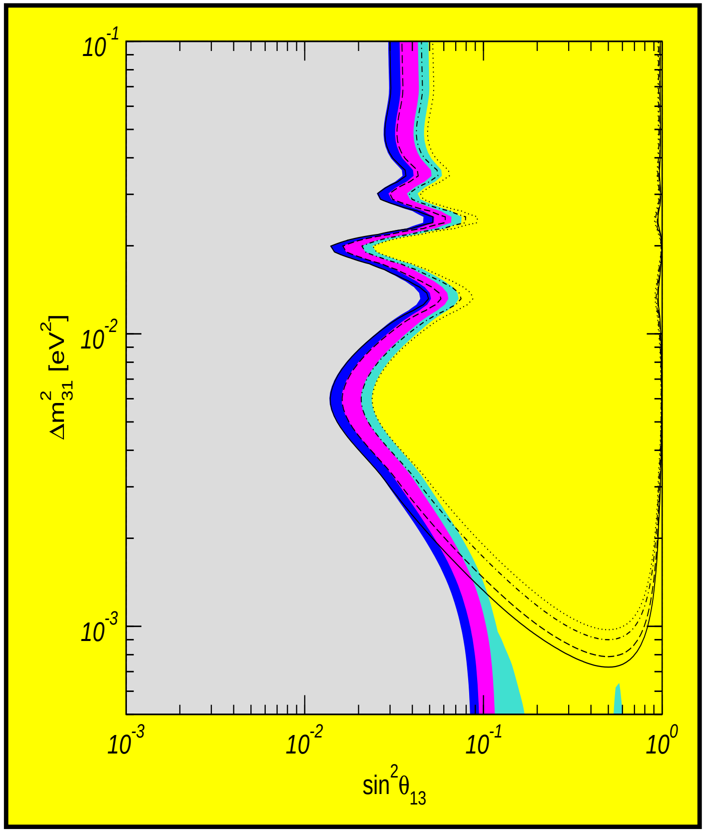
“Dirac” CPV suppressed, since δ disappears when any $\Delta_{ij} \to 0$

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

correlation with $\Delta m^2_{\mathrm{SOL}}$ and θ_{13}

determining $\alpha = \Delta m^2_{\text{SOL}}/\Delta m^2_{\text{ATM}}$ and θ_{13}





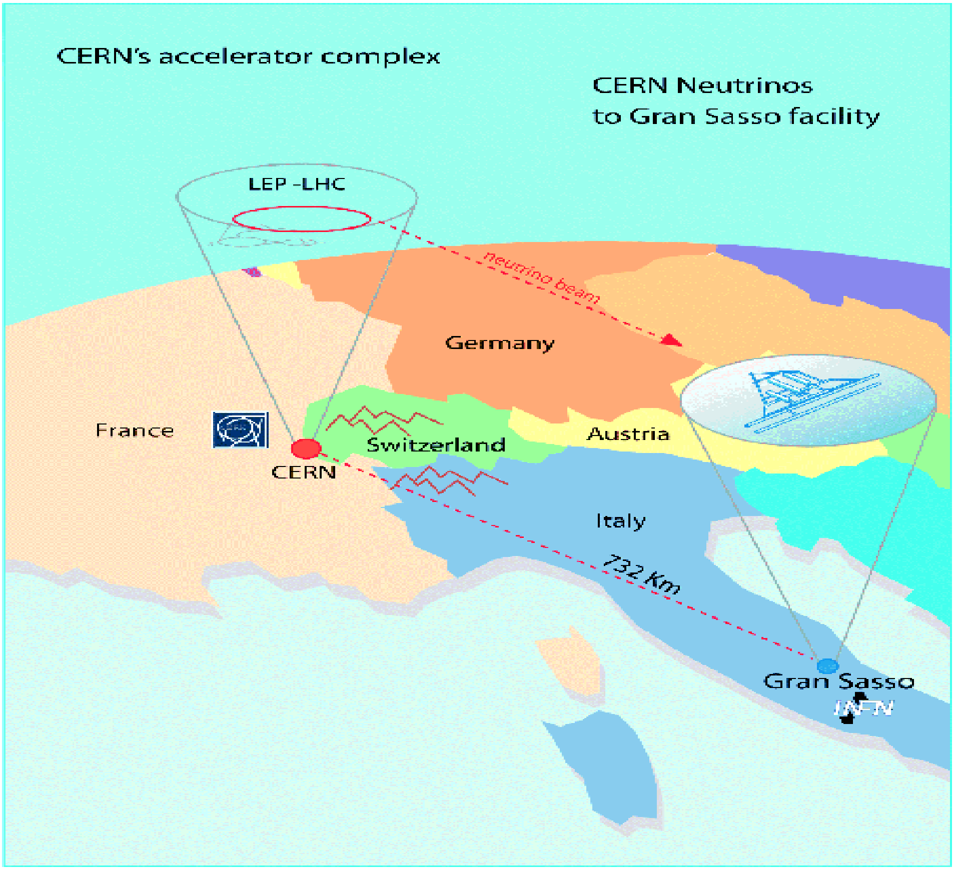
for low Δm^2_{ATM} the solar SNO-salt bound becomes relevant

Neutrino Factories

will probe s_{13} and CP phase δ

Cervera et al, De Rujula, Gavela, Hernandez

Freund, Huber, Lindner, Albright et al, Barger et al...



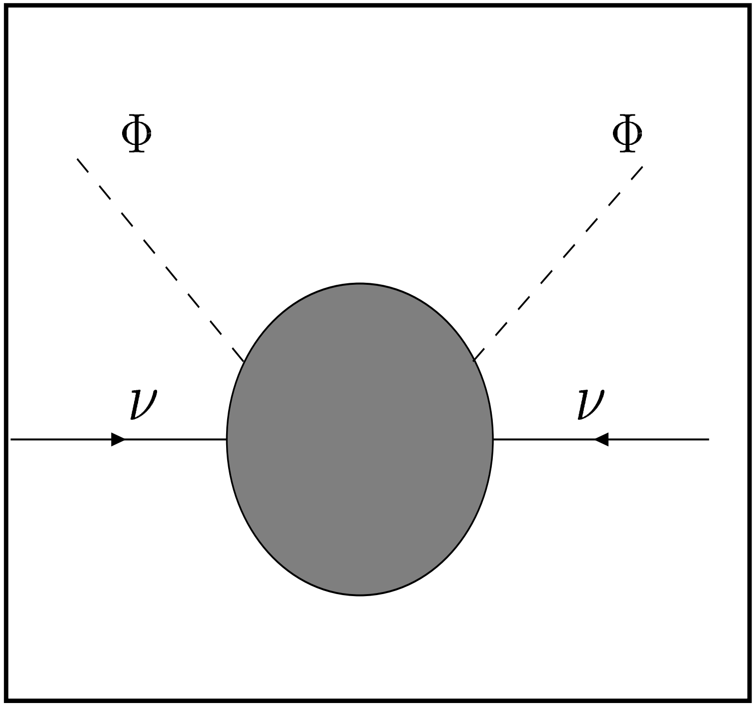
provided Non-Standard nu-Intercations (NSI) can be rejected ...

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

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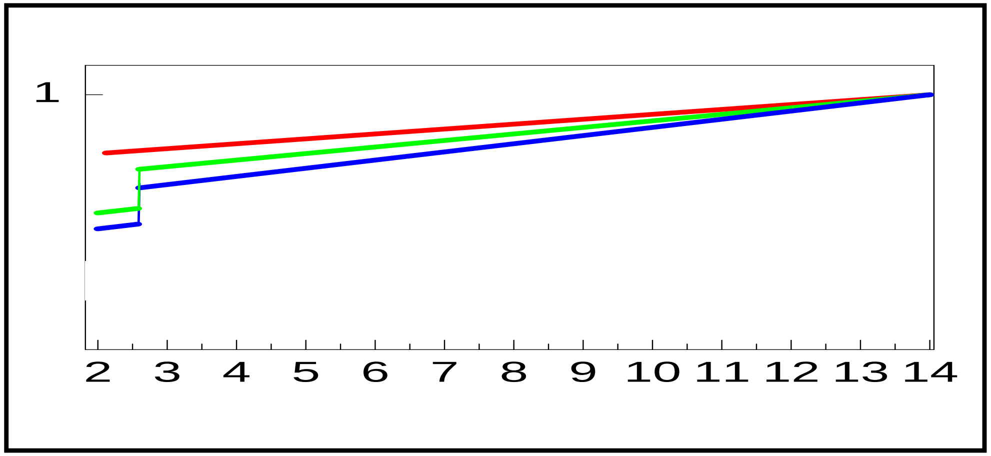
Babu, Ma and Valle, PLB552 (2003) 207

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

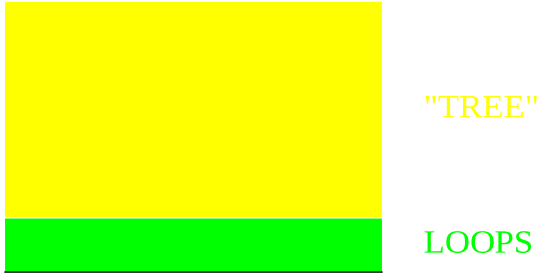
observable neutrino mass eg in cosmology, β and $\beta\beta_{0\nu}$ decays

observable Lepton Flavor Violation

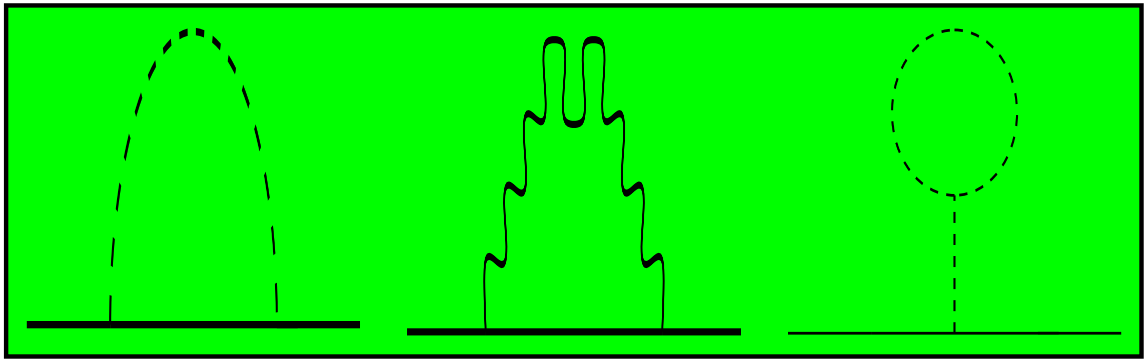
bilinear R parity violation: weak-scale seesaw

Diaz etal PRD68 (2003) 013009 [hep-ph/0302021]; PRD62 (2000) 113008 [Err-ibid. D65 (2002) 119901]; PRD61 (2000) 071703

- weak-scale seesaw atm scale

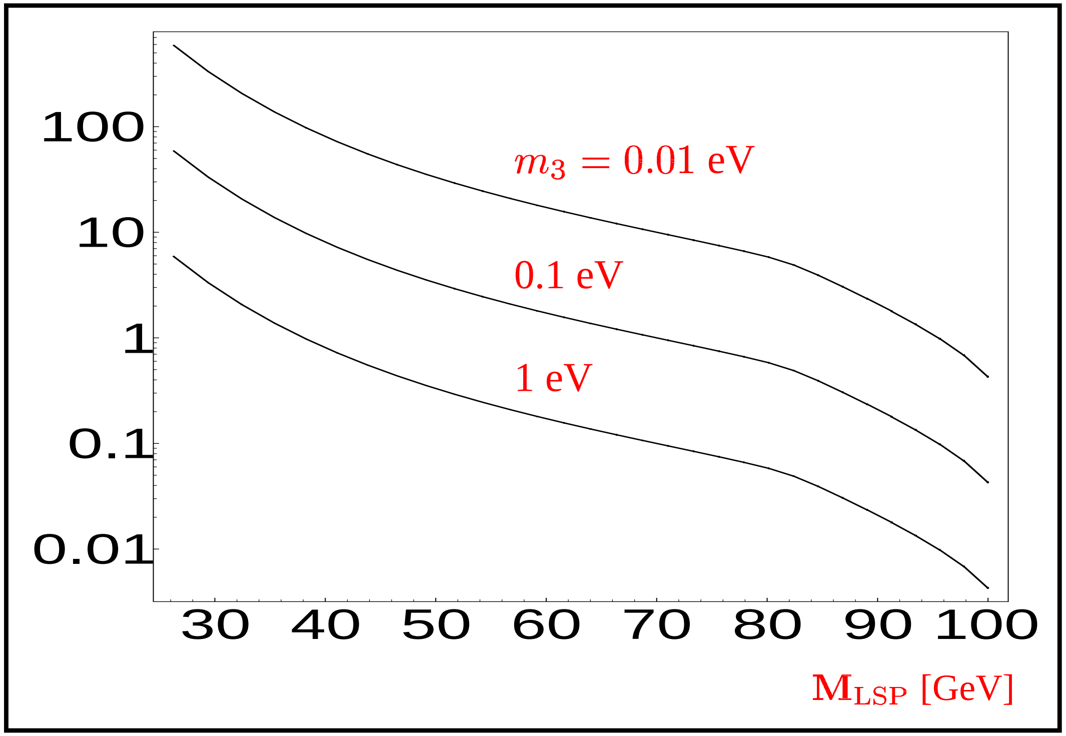


- radiative nu-masses solar scale



LSP decay length [cm]: BRPV

- from Bartl et al NPB 600 (2001) 39



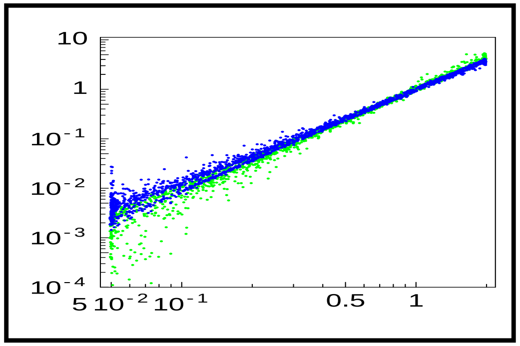
Mukhopadhyaya, Roy & Vissani; Chun & Lee; Choi et al; Datta et al

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 given as RPV ratios, e,g, atm mixing

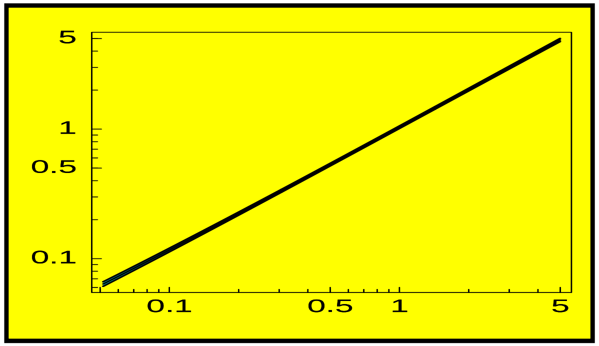


$\tan^2_{23}$ vs (Λ_2/Λ_3)

- LSP decay properties correlate with angles

neutralino

Porod et al PRD63 (2001) 115004



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

- stop decays
  slepton decays
  any LSP

Restrepo, Porod & Valle, PRD64 (2001) 055011

M. Hirsch et al, PRD66 (2002) 095006

Hirsch & Porod hep-ph/0307364

No Road Map to ultimate 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**
- sterile-nus? Are oscillations the end of the road?
- not the end, nor the beginning of the end, at best the end of the beginning...

http://ific.uv.es/~valle/talks/talks.html