“Neutrino physics before and after KamLAND”

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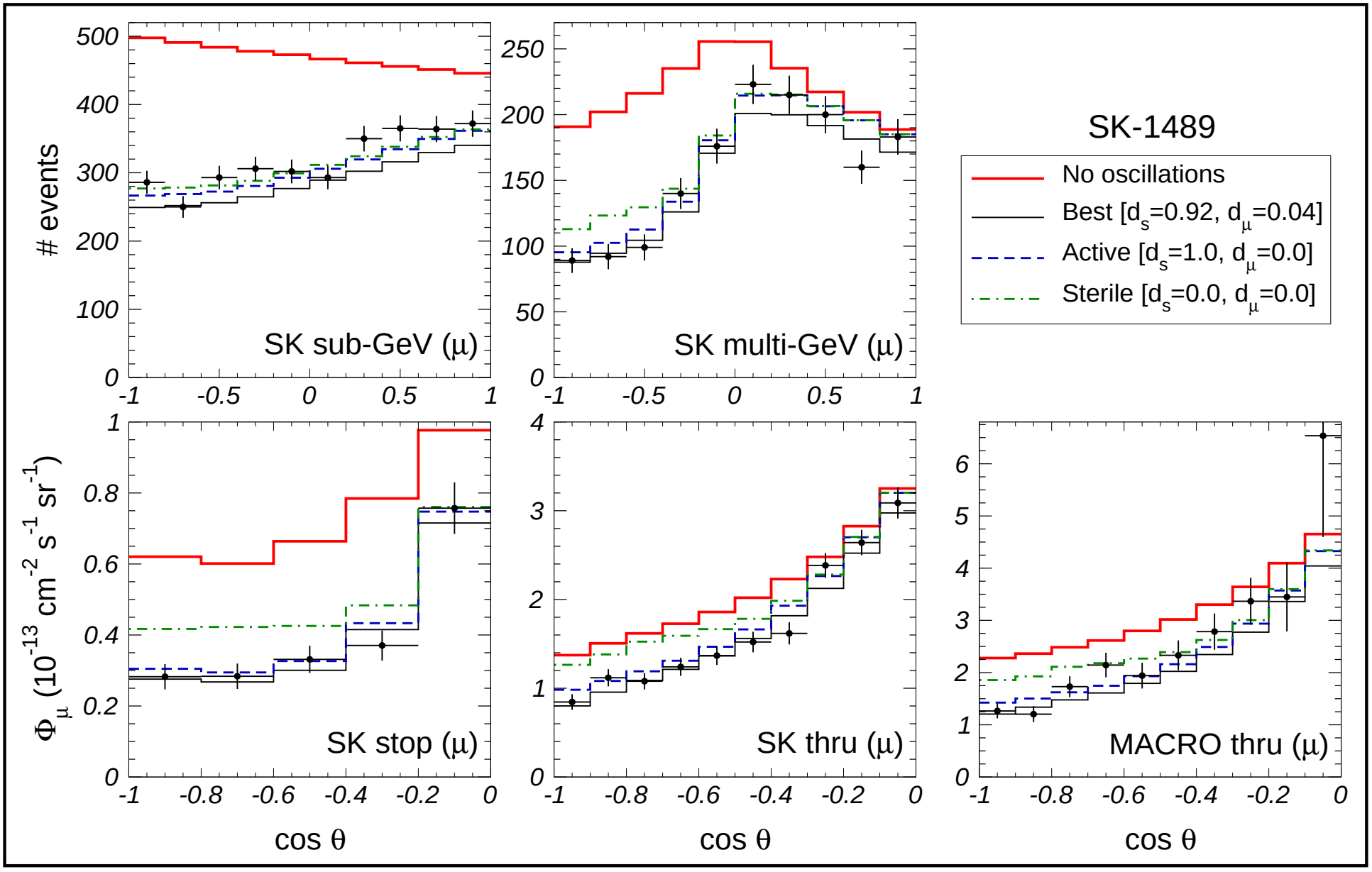
Based on review

S. Pakvasa and JV hep-ph/0301061

Atmospheric zenith distribution

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

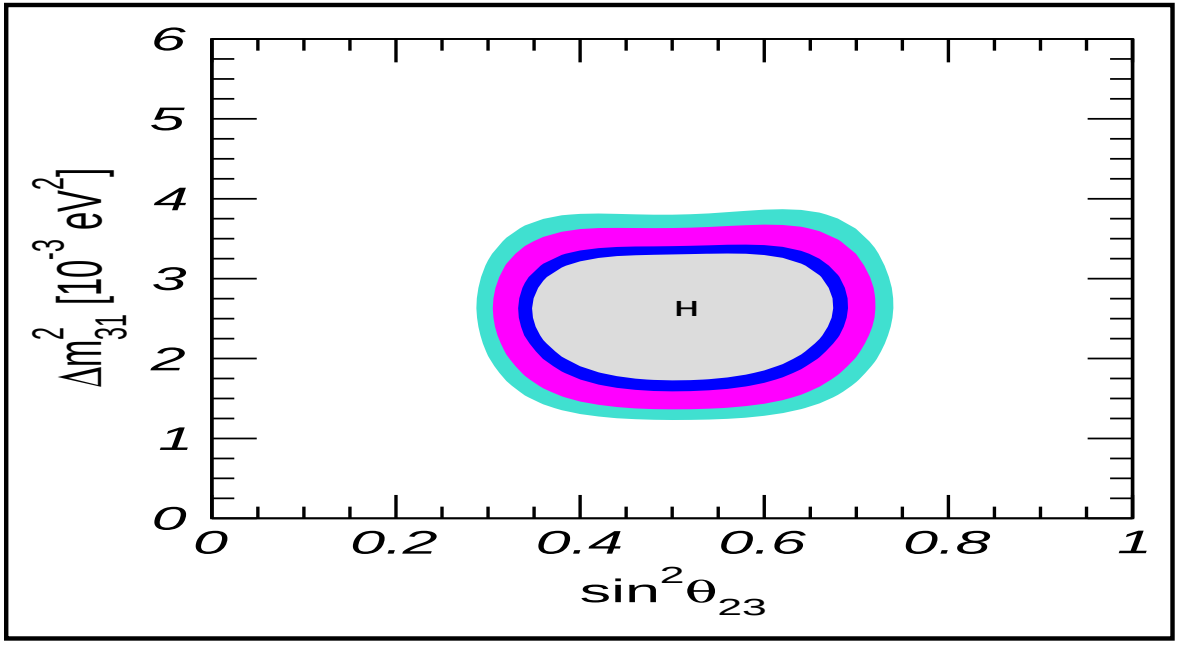


atmospheric neutrinos

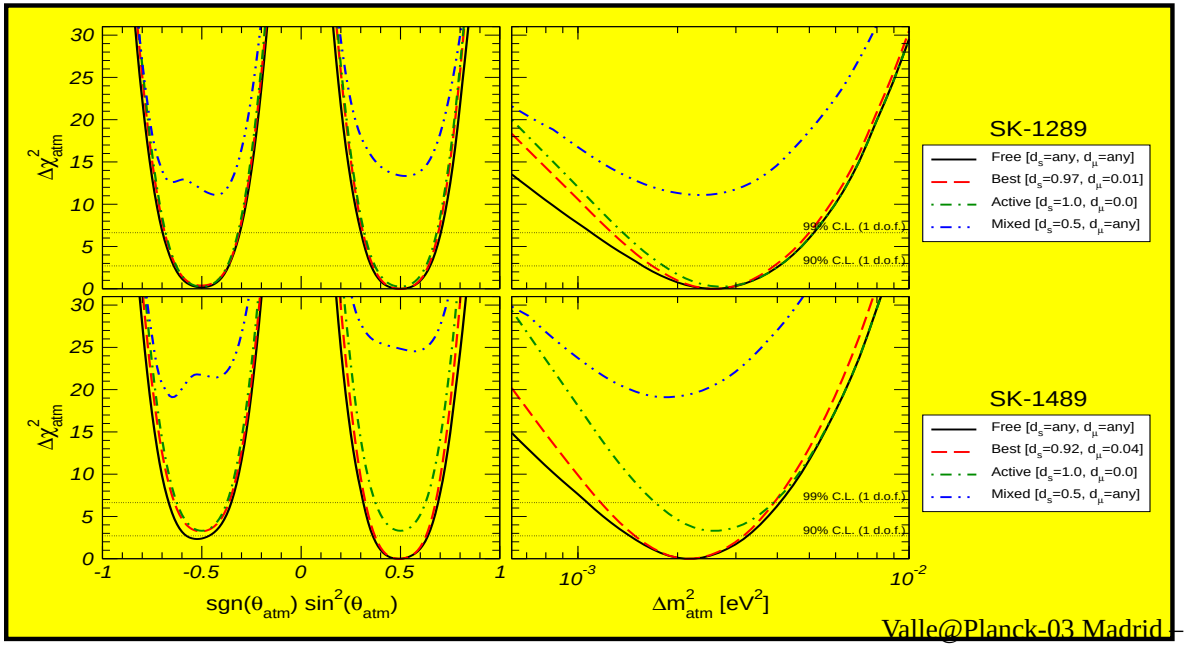
Maltoni et al PRD67 (2003) 013011

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

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



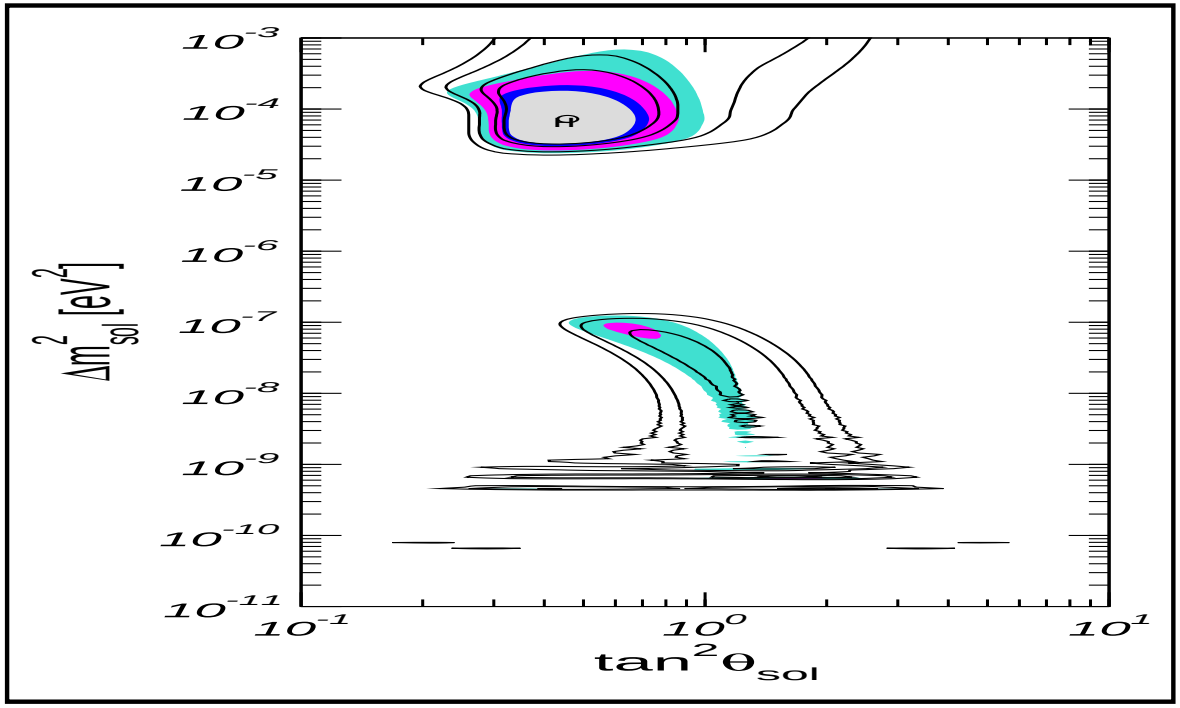
higher sterility rejection

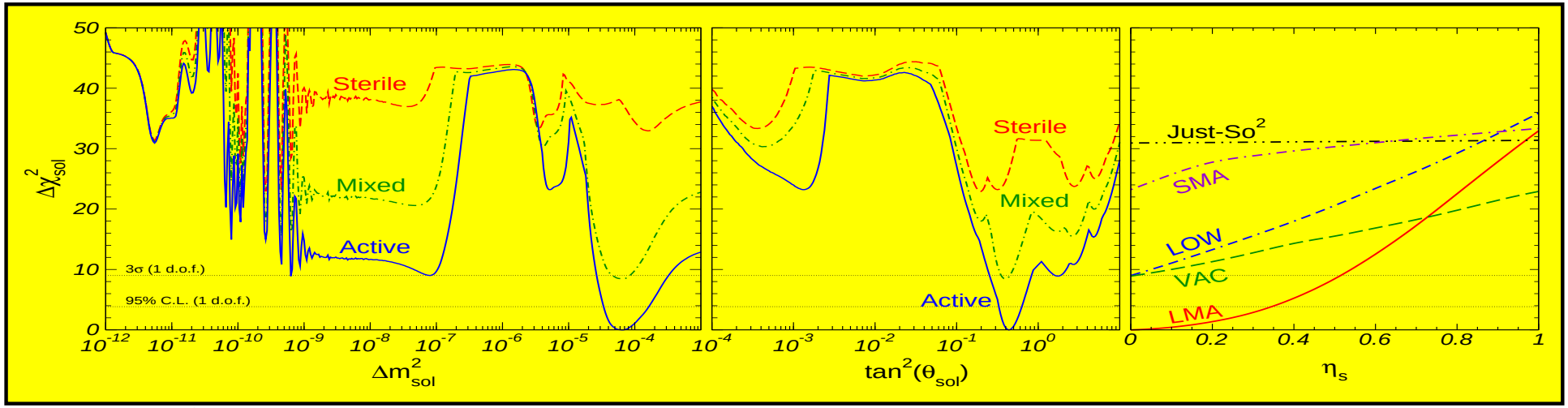


solar-only oscillation regions

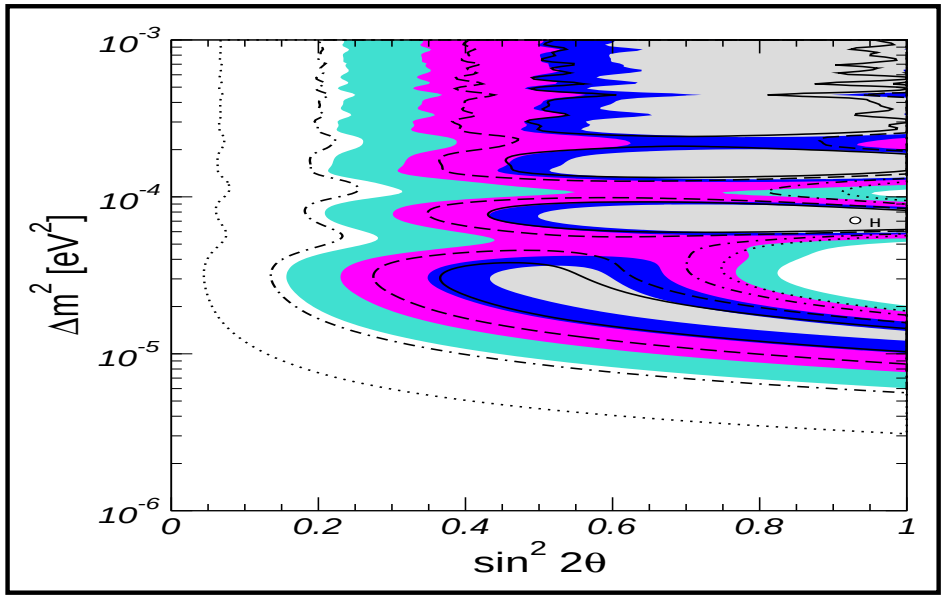
Maltoni et al, PRD67 (2003) 013011 (cf different groups)

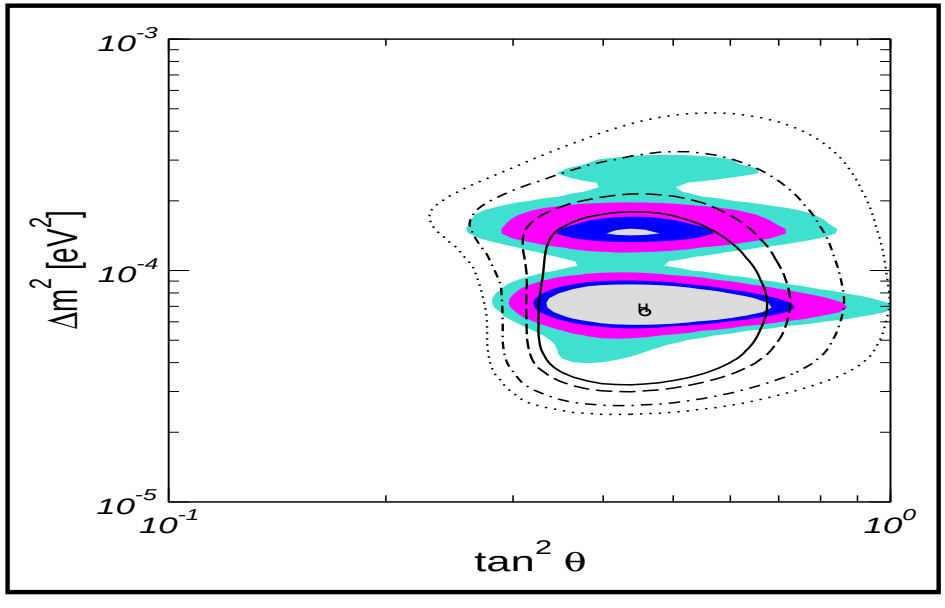
previous LMA-MSW hint came from spectrum, Gonzalez-Garcia et al, NPB573 (2000)3





Implications of first KamLAND reactor results





Maltoni, Schwetz & JV, PRD67 (2003) 093003

first 145-days data support oscillation hypothesis

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

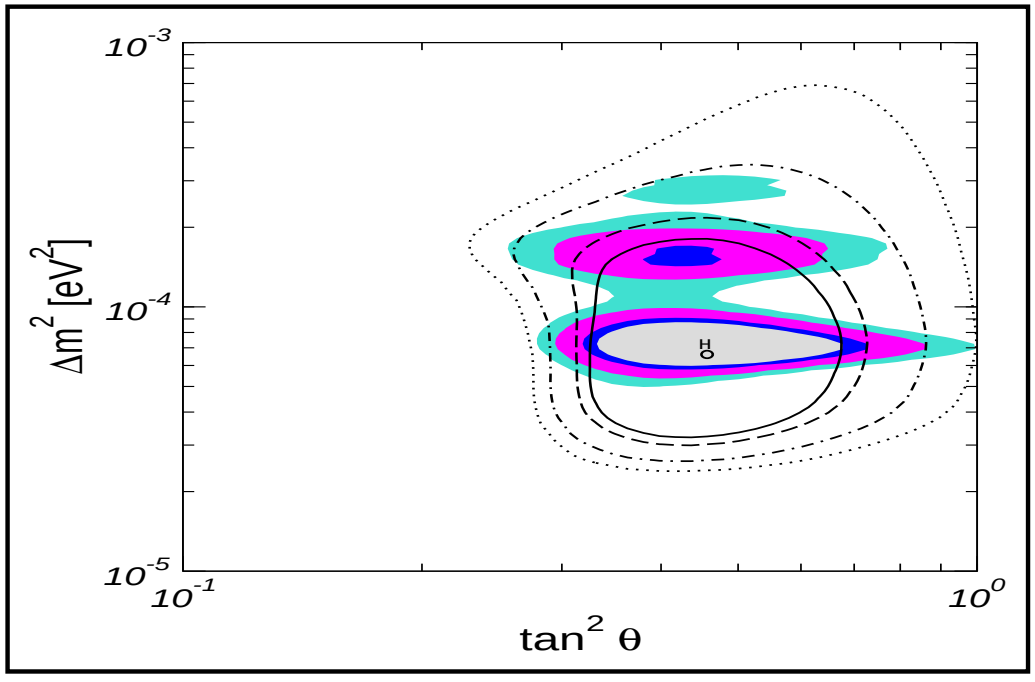
$\Rightarrow$ **oscilllations happen inside the sun!**

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

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

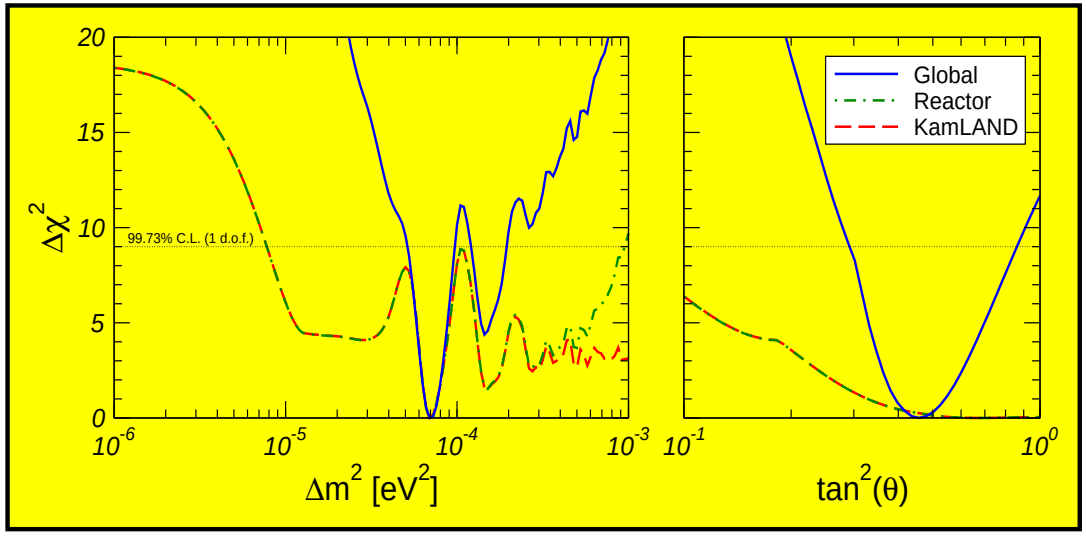
$$1.2 \times 10^{-4}\ \mathrm{eV}^2 \leq \Delta m^2_{\mathrm{SOL}} \leq 1.9 \times 10^{-4}\ \mathrm{eV}^2.$$

Solar + KamLAND results



Maltoni, Schwetz, JV, PRD67 (2003) 093003

consistency with Poisson method



in contrast to atmospheric, solar mixing remains significantly non-maximal

bi-maximal models rejected

Robustness of MSW plot

neutrino propagation strongly affected by density noise

Balantekin et al 95

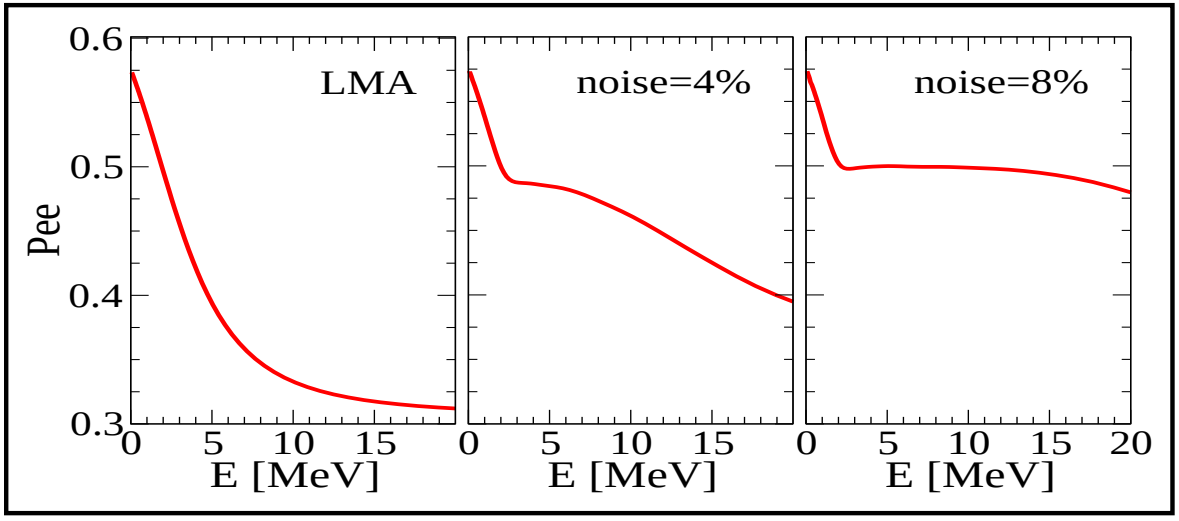
Nunokawa et al NPB472 (1996) 495

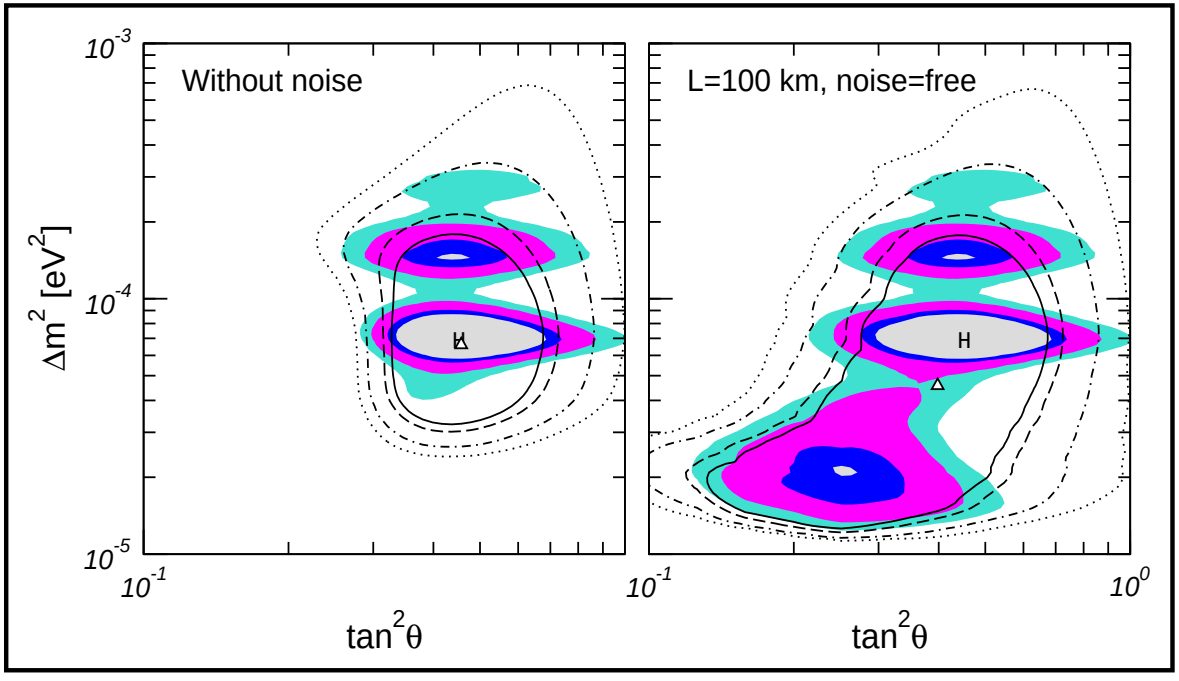
Burgess et al 97

substantial distortion

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

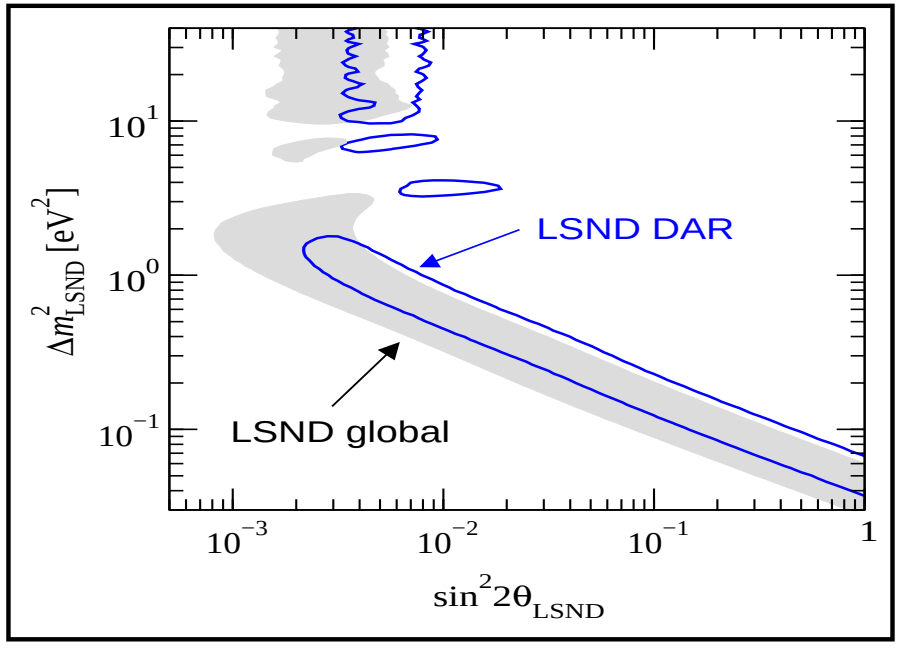
Burgess et al, Astrophys.J.588:L65,2003 [hep-ph/0209094]





LSND

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



ATM

Peltoniemi, JV, NPB **406**, 409 (1993)
Peltoniemi, Tommasini and JV, PLB **298** (1993) 383

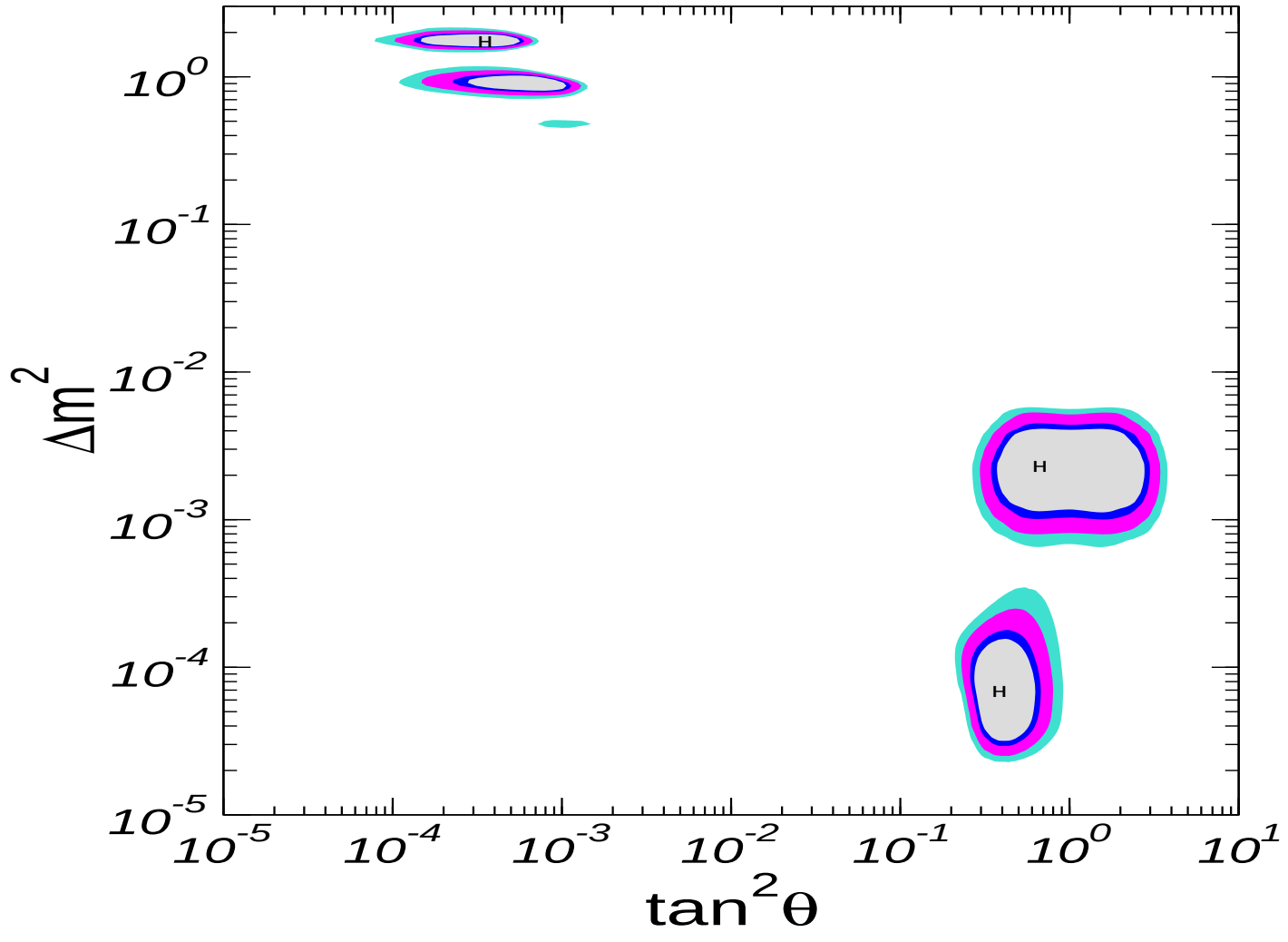
Caldwell-Mohapatra PRD48 (1993) 325

http://www.to.infn.it/~giunti/neutrino/

SOL

can one fit all current nu-data with oscillations ?

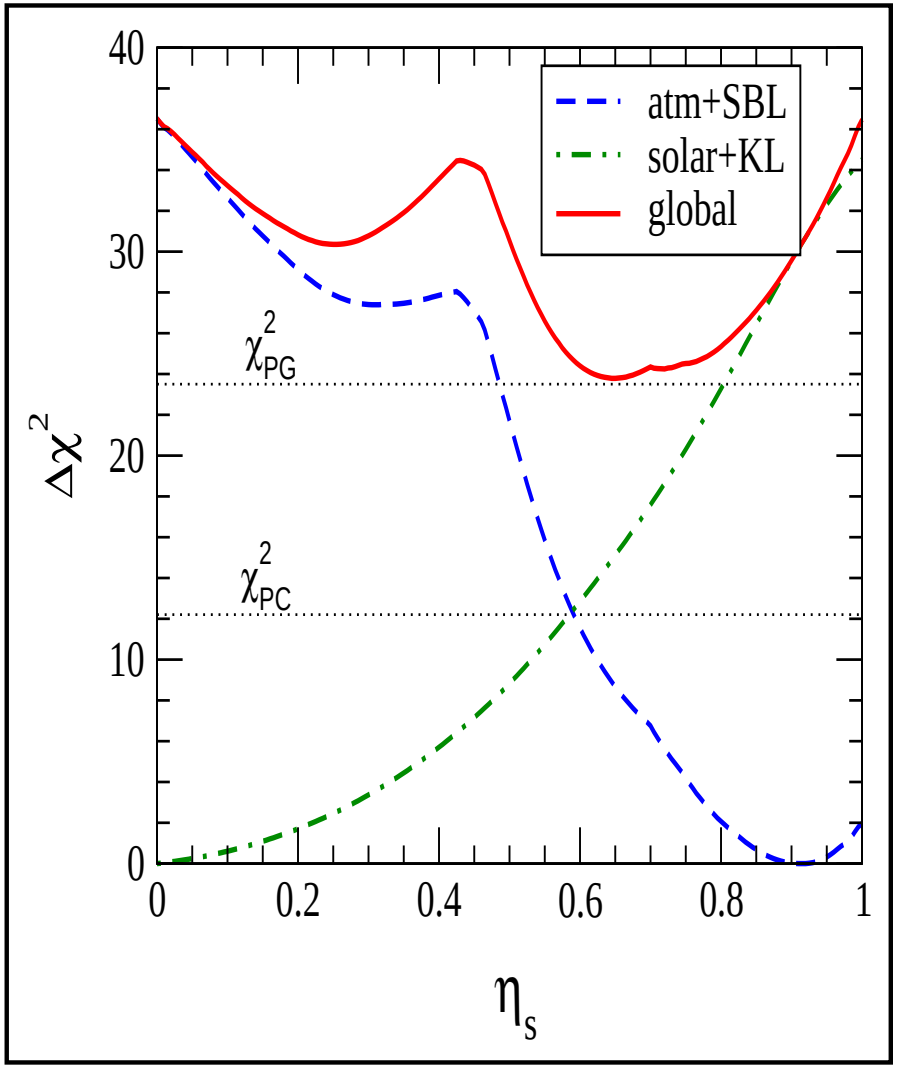
sol+atm+reac+**sbl/lsnd**

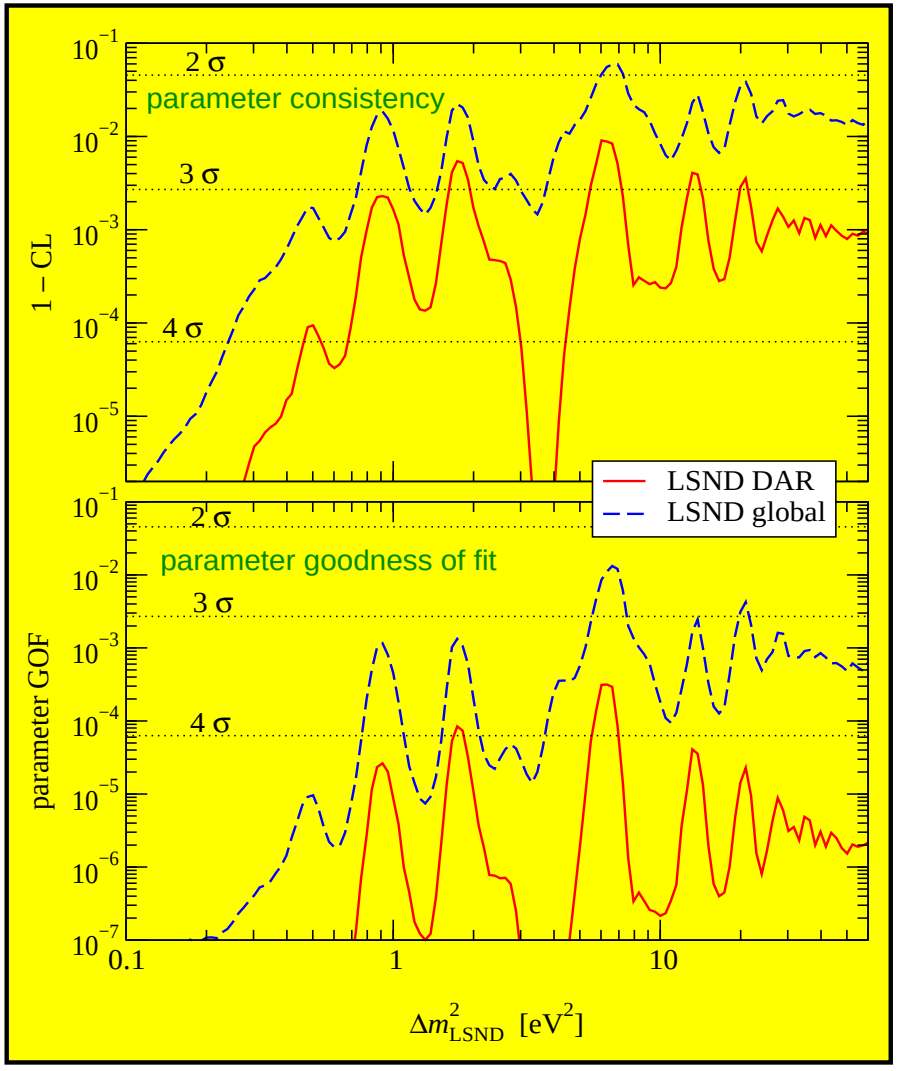


4-nus do not fit LSND with sol+atm

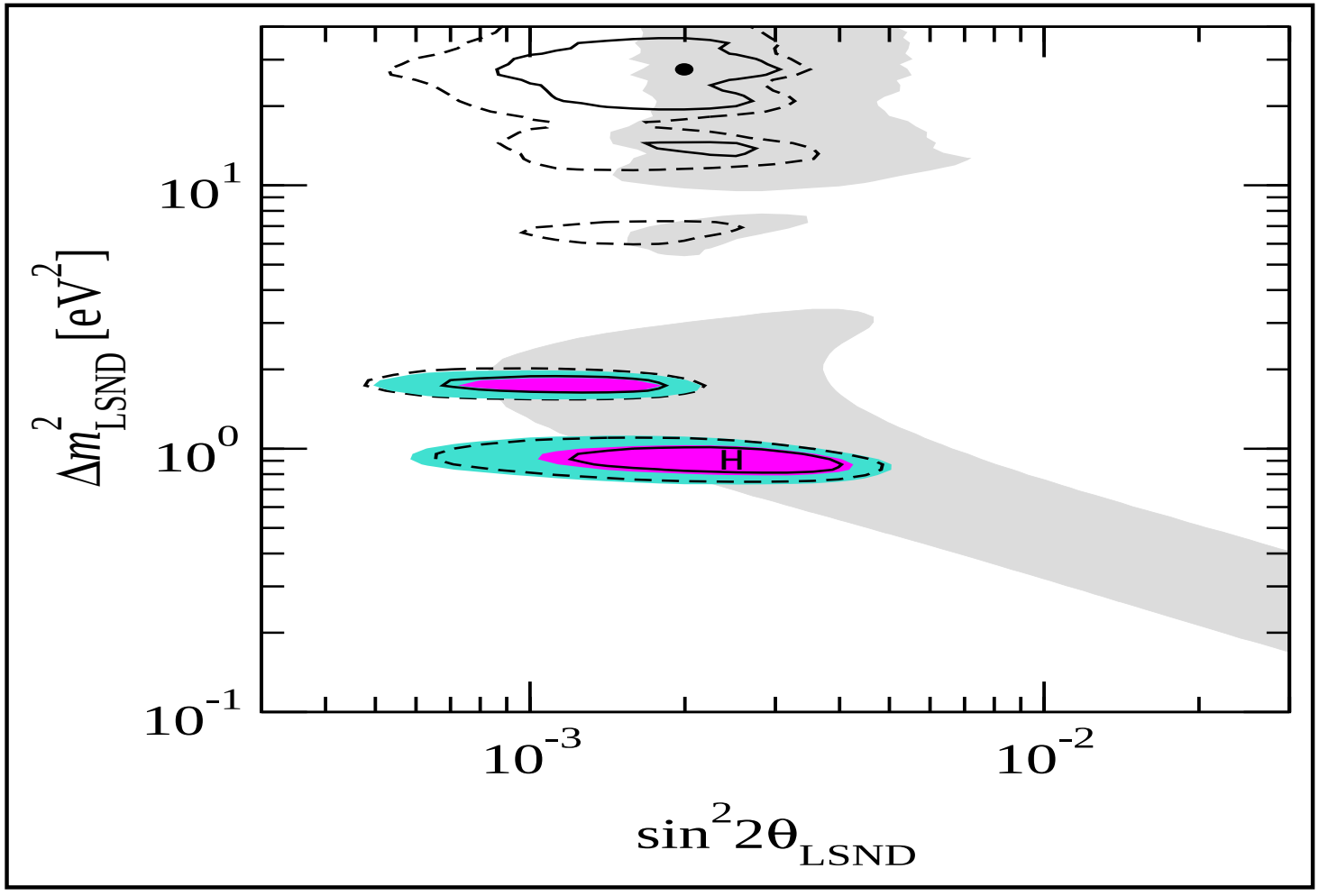
Maltoni et al NPB643 (2002) 321; upd of PRD65 (2002) 093004

stronger rejection by solar & atm in 2+2 than 3+1





Cosmology closes in on LSND



Schwetz et al hep-ph/0305312

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

Absolute neutrino mass scale

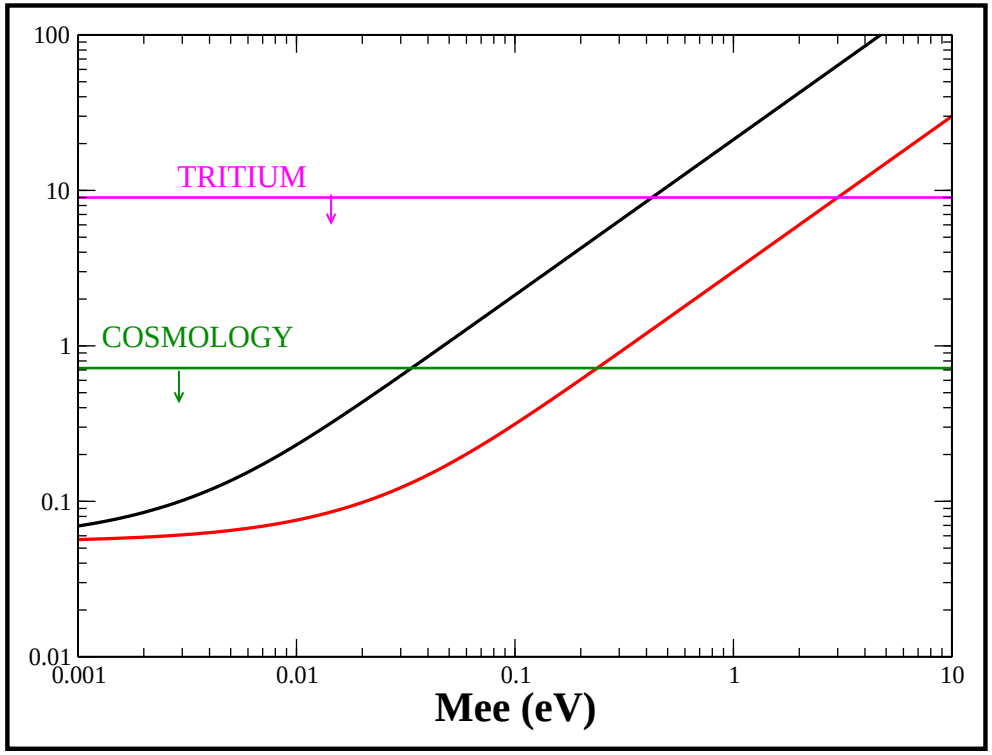
in contrast to oscillations

cosmology can probe absolute m-nu scale

tritium beta decay experiments

CMB bound on hot dark matter component (2DF, WMAP, ...)

neutrinoless double beta decay

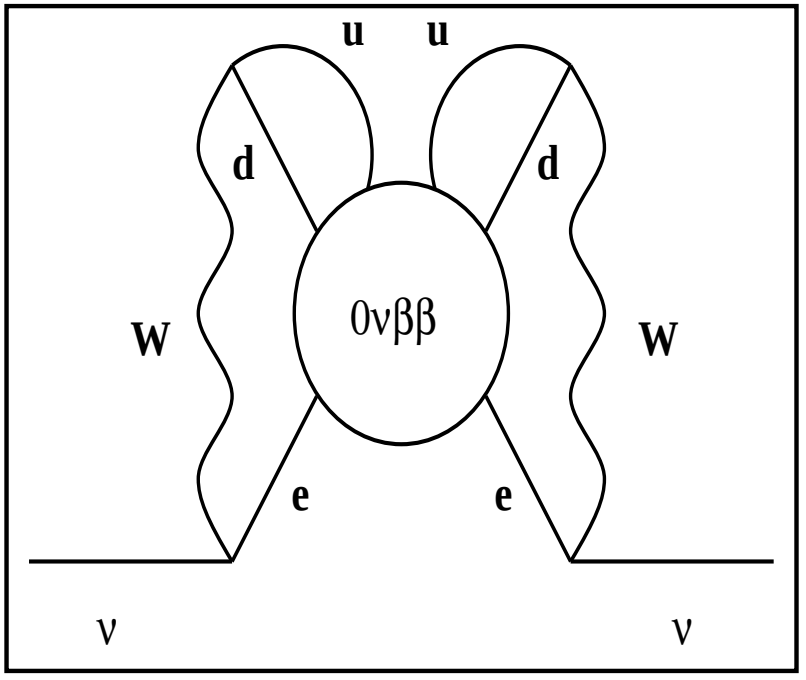


Barger, Glashow, Marfatia and Whisnant, PLB532 (2002) 15; Vissani, JHEP **9906**, 022 (1999)

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

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

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



like other L violating processes
$\beta\beta_{0\nu}$ is sensitive to Majorana phases

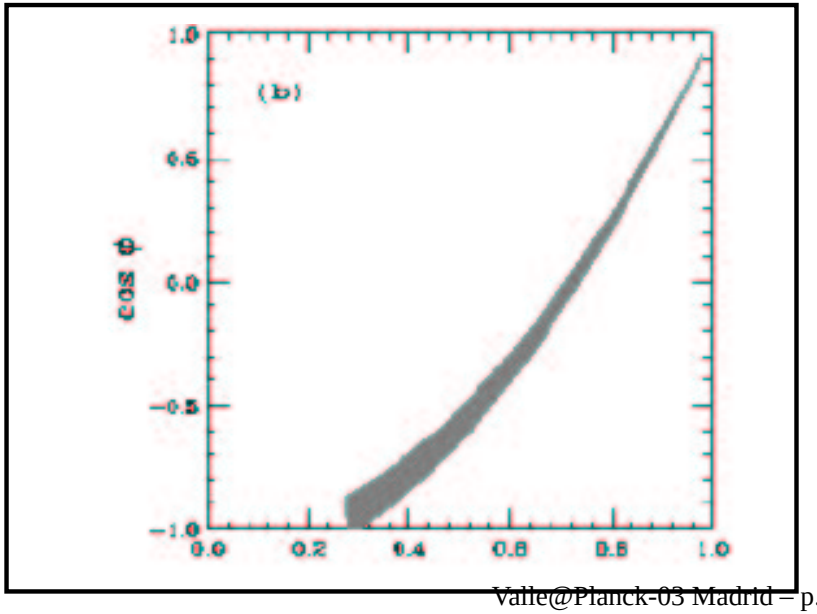
Schechter and JV, PRD22 (1980) 2227, D23 (1981) 1666

Wolfenstein PLB107 (1981) 77; Doi et al

can not reconstruct majorana phases

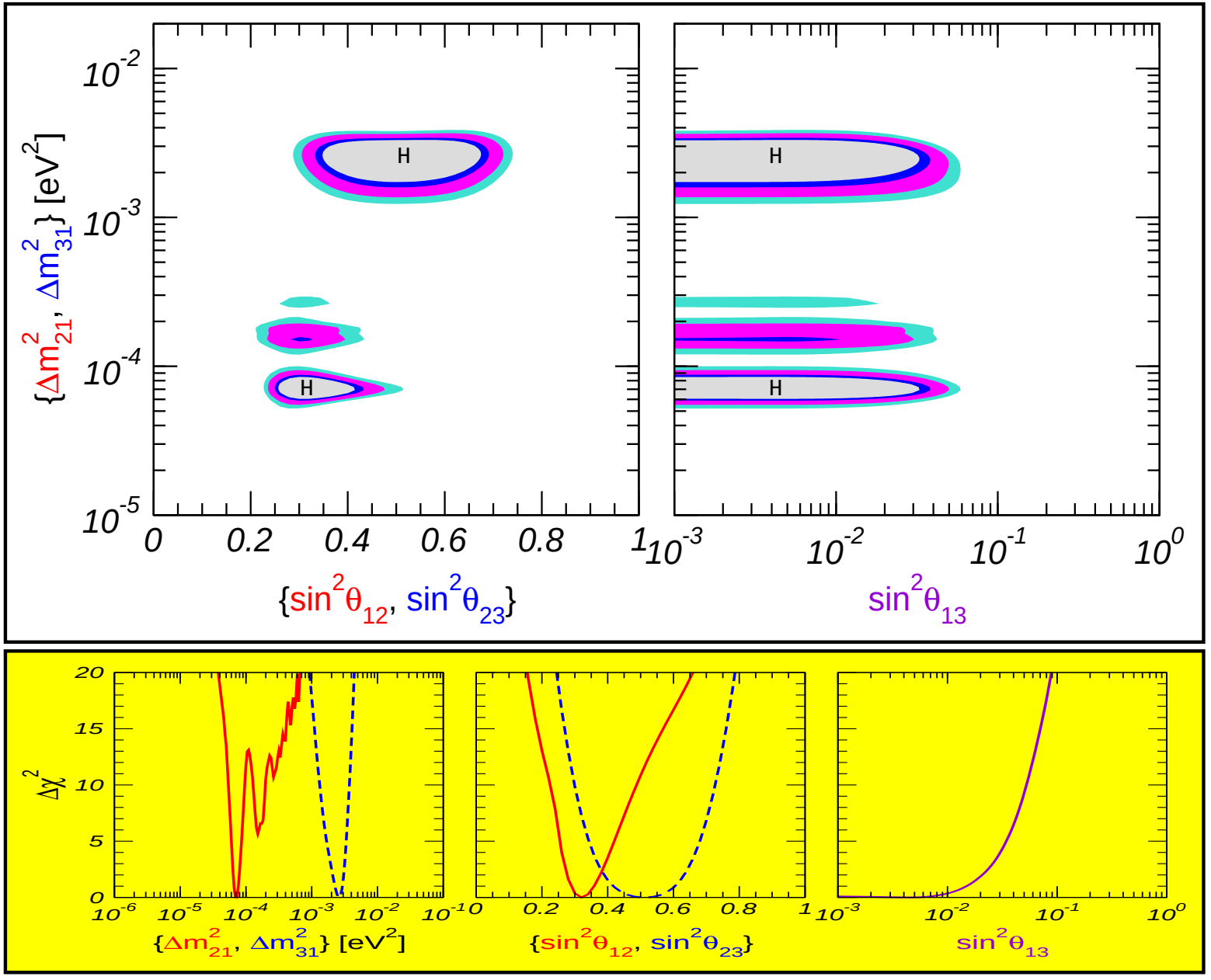
Barger, Glashow, Langacker, Marfatia, PLB B540 (2002) 247

a pity for leptogenesis



neutrino parameters in a nut shell

Maltoni et al, PRD67 (2003) 013011



θ_{13} and Leptonic CP Violation

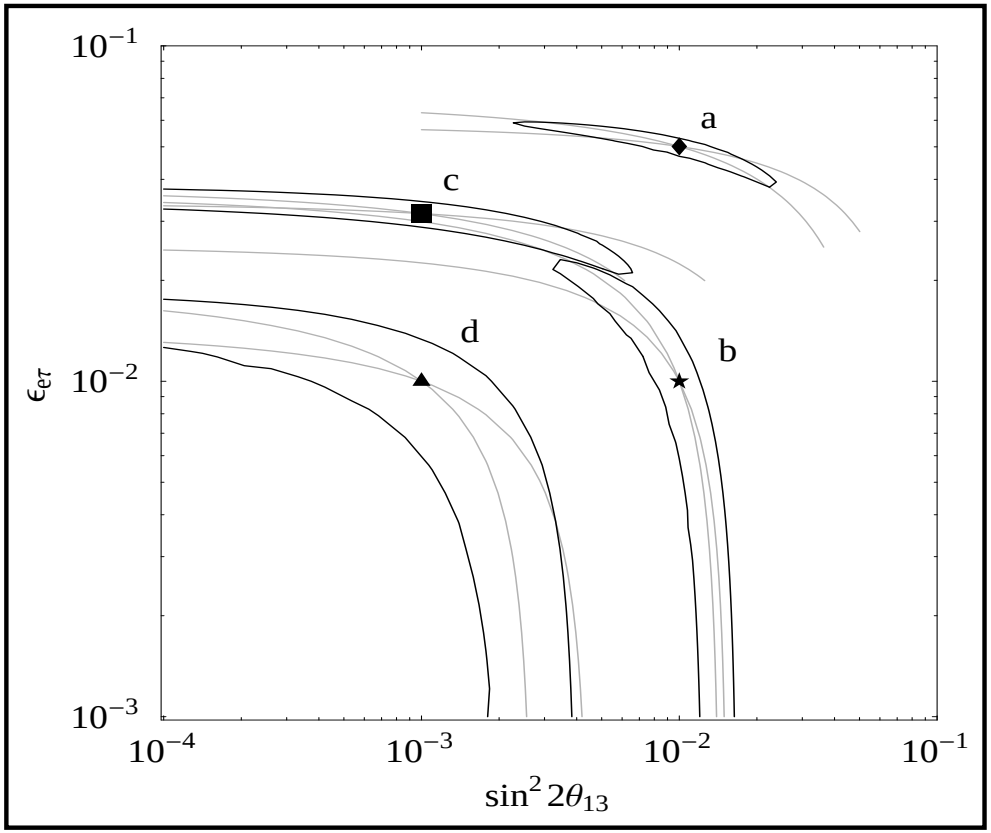
"Dirac" CPV suppressed, since ϕ disappears when any $\Delta_{ij} \to 0$

Schechter and J. V., PRD **21** (1980) 309

FCI-oscillation confusion theorem

a neutrino factory is less sensitive to θ_{13} because non-standard neutrino interactions are confused with oscillations

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



near-site programme essential

2×10^{20} mu/yr/polarity $\times$ 5 yr, 40 kt magn iron calorim, 10% muon E-resoln above 4 GeV

Theory of neutrino properties

how to reconstruct the parameters

how to reconstruct the underlying Theory

simplest gauge theory mixing matrix

- 3 angles θ_{ij}

  23=atm 12=sol 13=reac

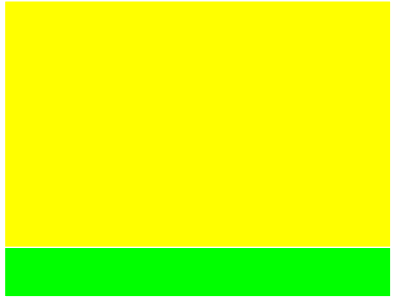
  1 KM-like ϕ

  2 Majorana phases $\beta\beta_{0\nu}$ & leptogenesis ϕ_1 , ϕ_2

Schechter and JV, PRD22 (1980) 2227

- max θ_{23}, large θ_{12} & small θ_{13} hierarchical splittings

normal

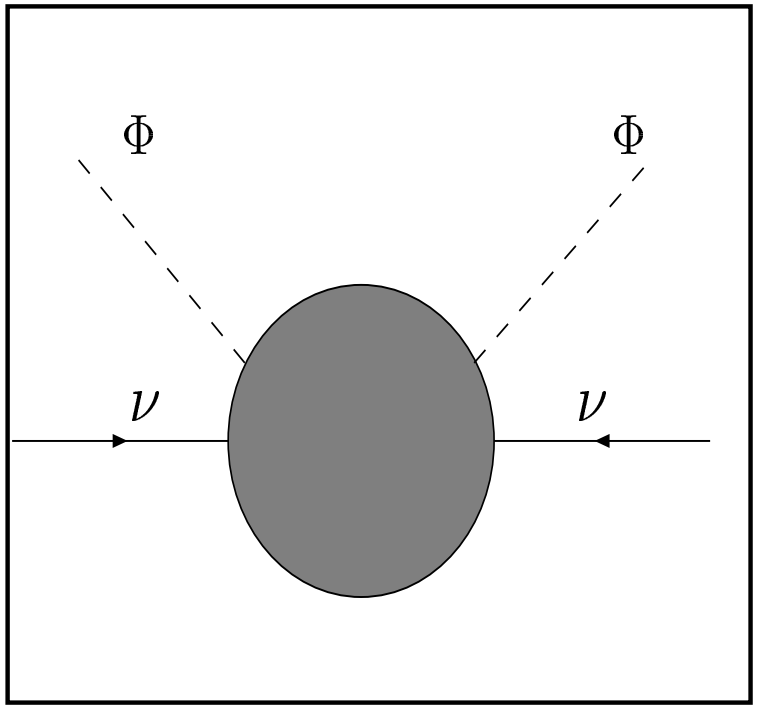


inverse

quasi-degenerate may lead to $\beta\beta_{0\nu}$ rate similar to present hint

Theory ideas

basic dim-5 operator back



- from Gravity

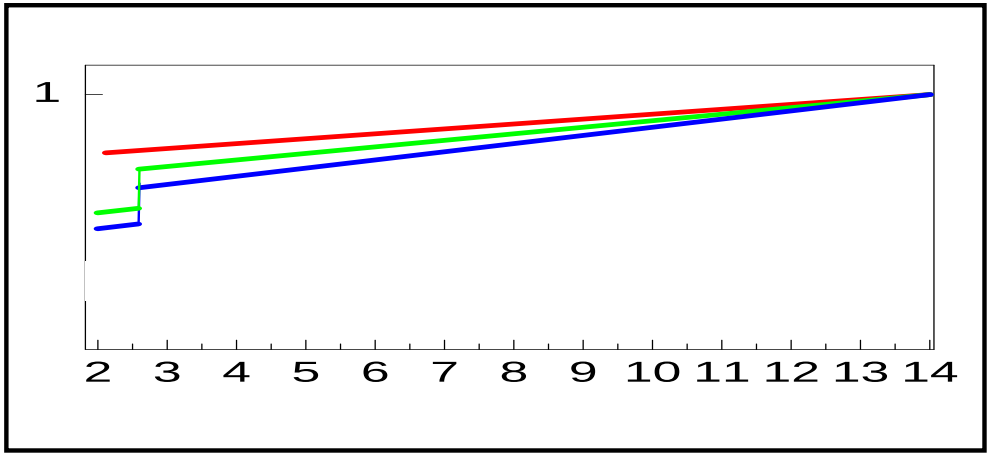
  Weinberg; Barbieri, Ellis, Gaillard; Zee & Weldon
- from seesaw schemes

  Gell-Mann, Ramond, Slansky; Yanagida;
  Mohapatra, Senjanovic PRL **44** (1980) 91
  Schechter, JV PRD **22** (1980) 2227
- weak seesaw

neutrino unification

back

Babu, Ma and Valle, PLB552 (2003) 207



neutrino masses unify as they run up

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

solar & atm splittings from RGE

common origin for neutrino and KM mixing

maximal θ_{23}; large θ_{12} & small θ_{13}

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

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

All Pathways to Neutrino Mass are Open

- top-bottom vs bottom-up
- hierarchical vs quasi-degenerate, sterile-nus?
- 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
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...
- **no theory of flavour**