

# “Neutrino properties before and after KamLAND”

J. W. F. Valle

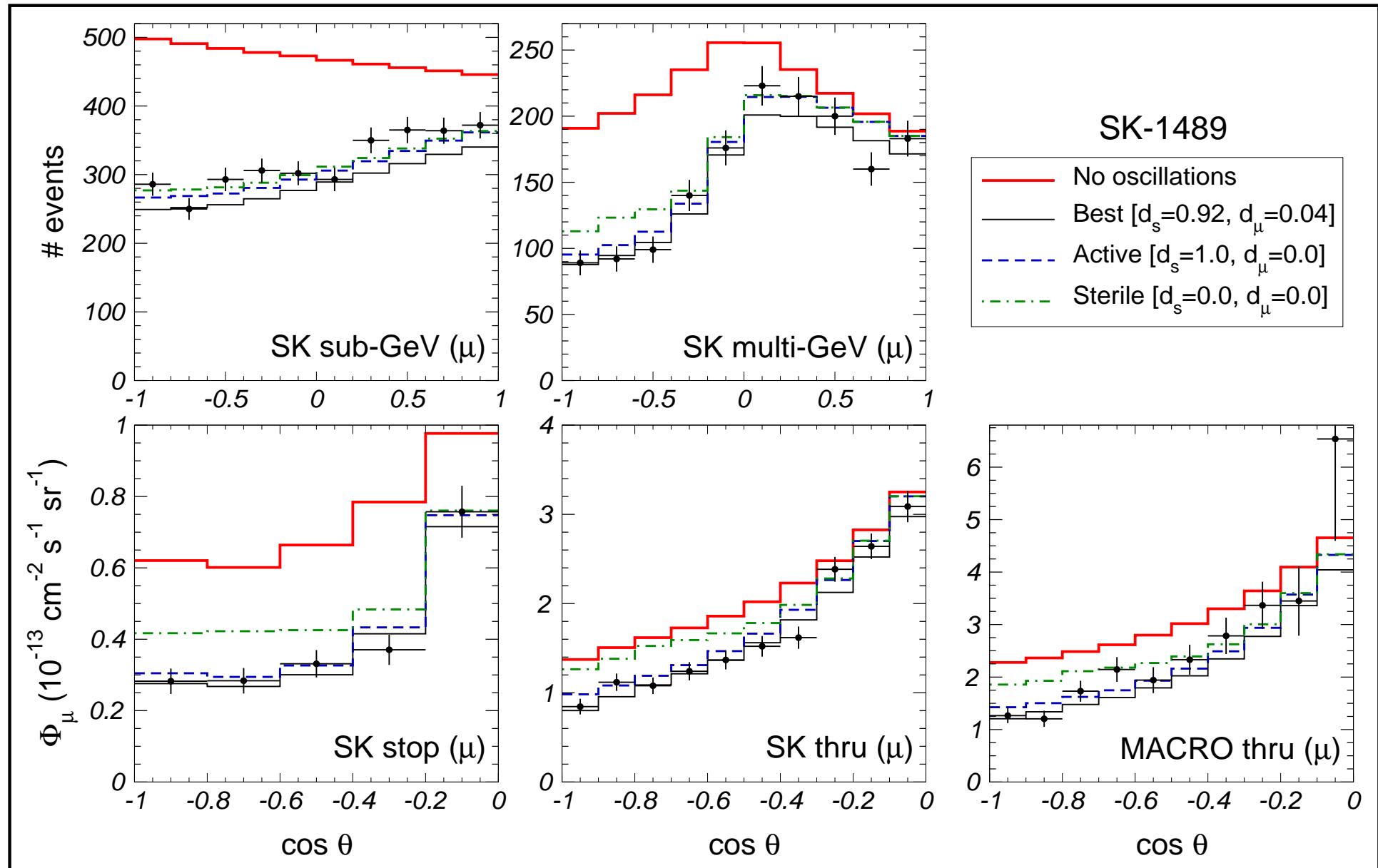
IFIC-CSIC/U. Valencia

based on review

S. Pakvasa and JV hep-ph/0301061

# Atmospheric zenith distribution

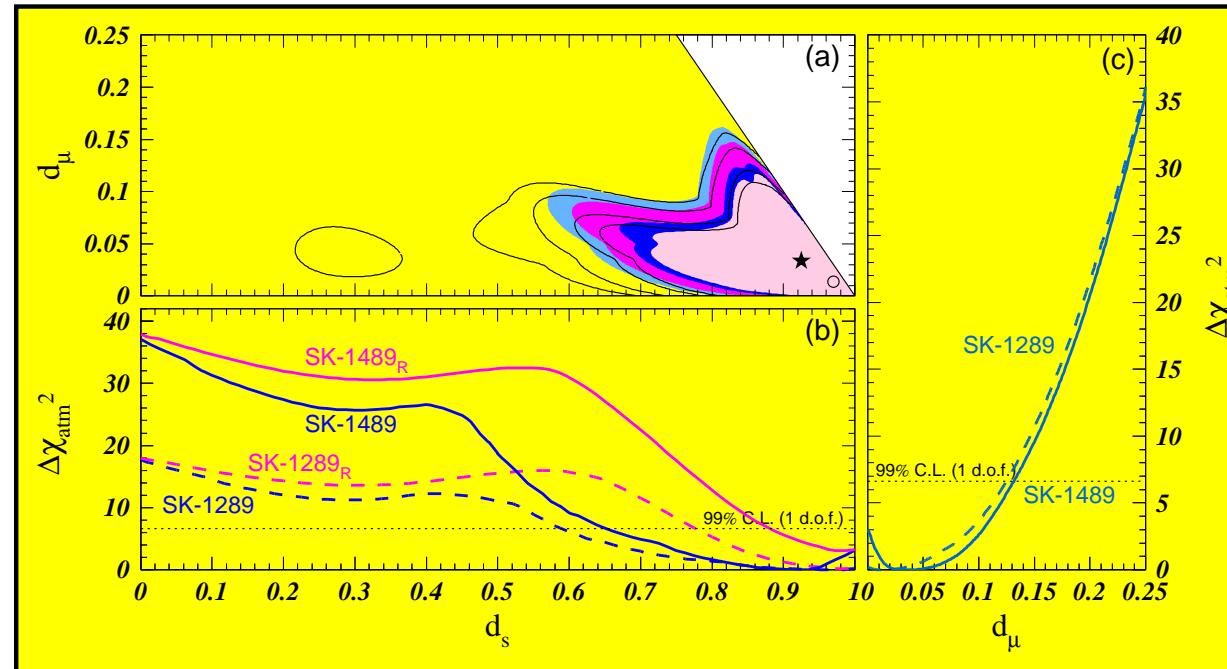
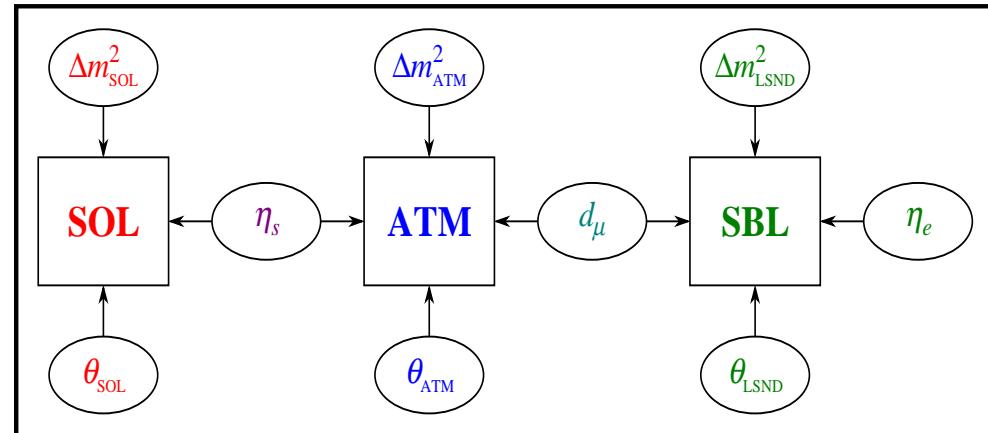
Maltoni, Schwetz, Tortola and Valle PRD **67** (2003) 013011



# new parameters in atmospheric analysis

sterile as 4th, not 2nd

neglecting CP phases there are  
6 angles in the lepton mixing  
matrix



sterility rejection sensitive to new parameters

# atmospheric neutrinos

1289 vs 1489-day samples

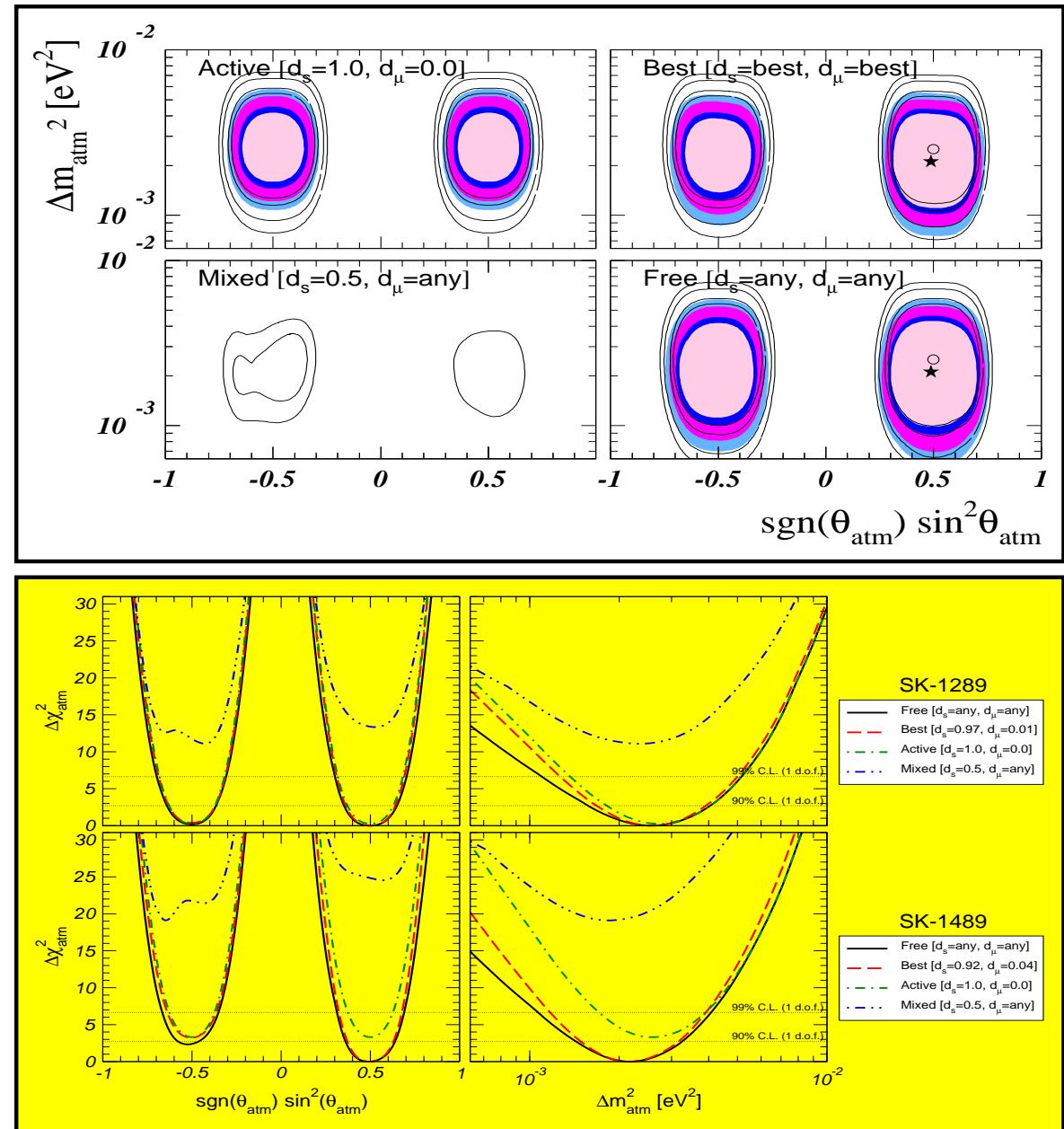
from Maltoni et al

PRD 67 (2003) 013011

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

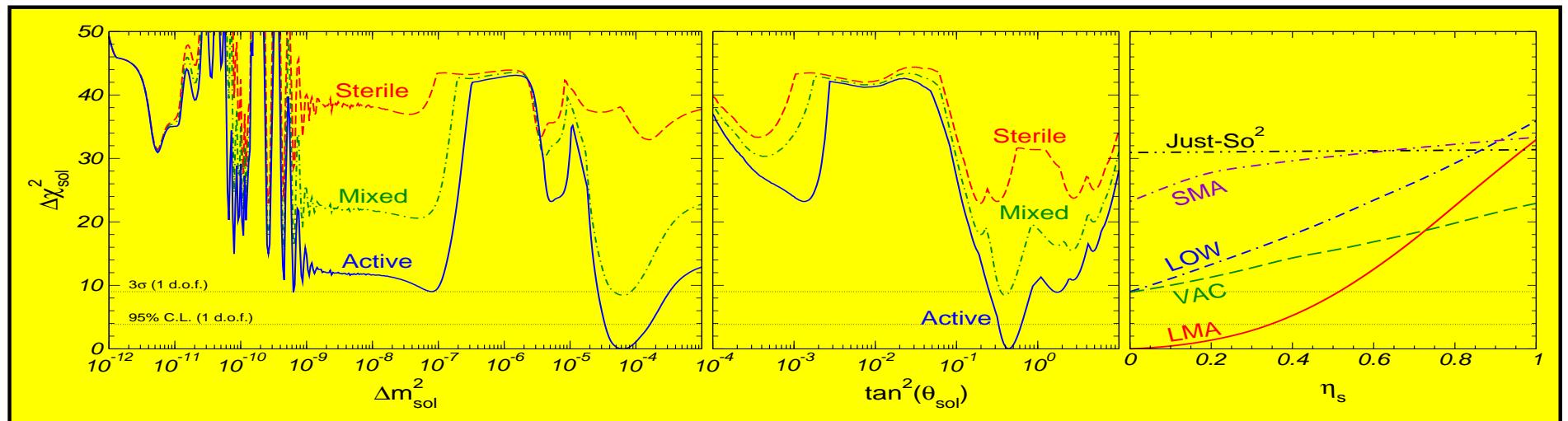
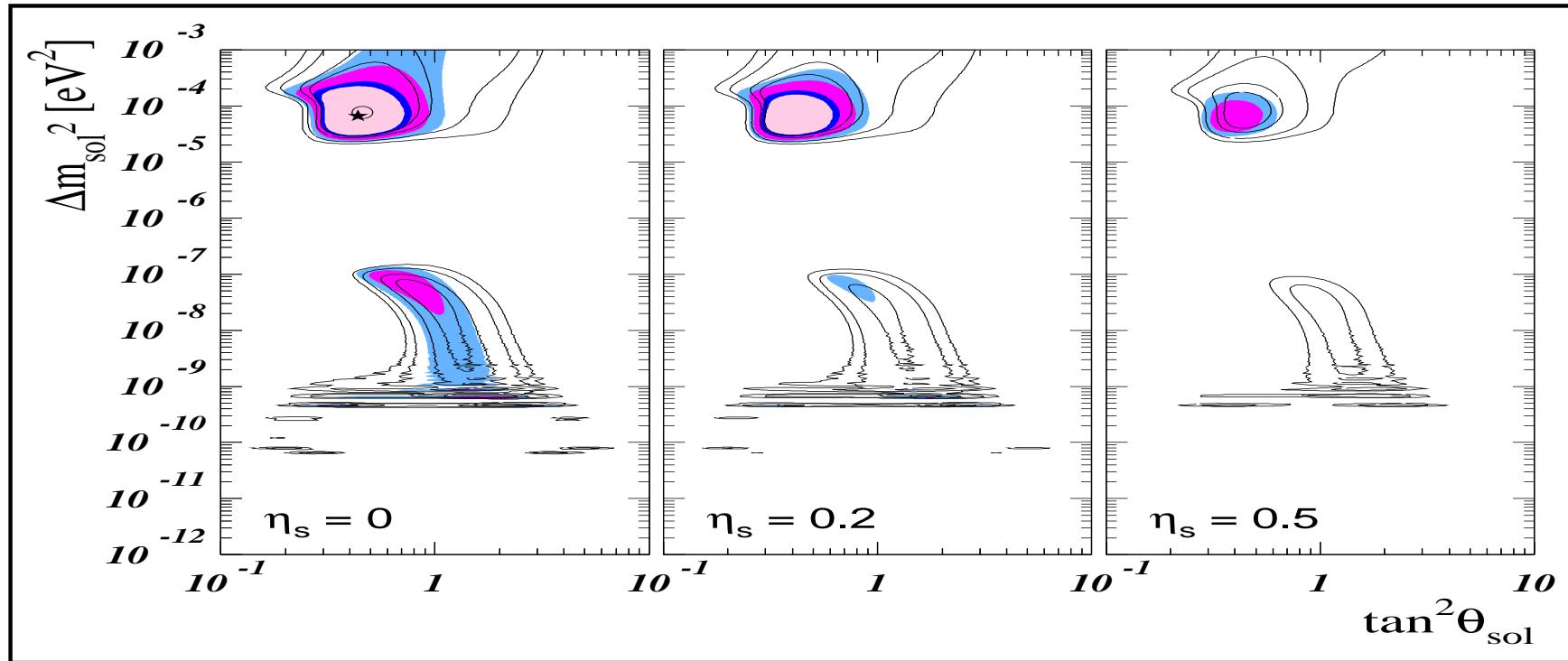
$$\Delta m_{\text{ATM}}^2 = 2.5 \times 10^{-3} \text{ eV}^2$$

higher sterility rejection

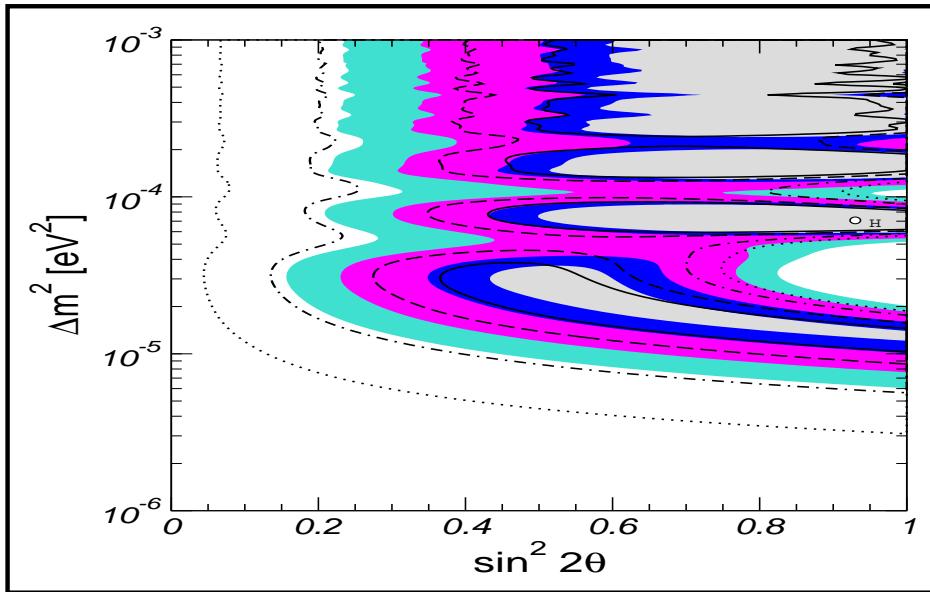


# solar-only oscillation regions

Maltoni et al, PRD **67** (2003) 013011 (cf different groups)

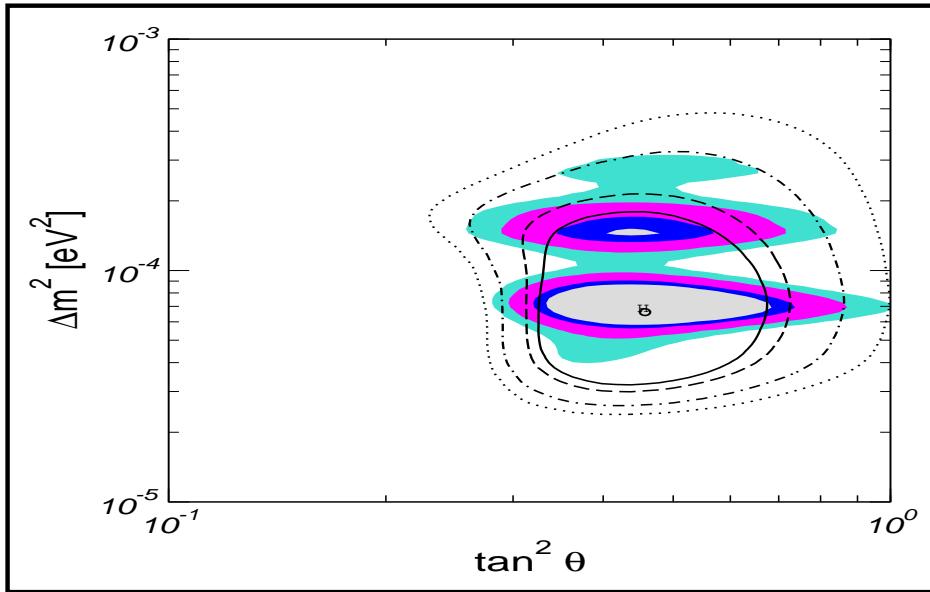


# Implications of first KamLAND reactor results



Maltoni, Schwetz & Valle, hep-ph/0212129

first 145-days data support oscillation hypothesis



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

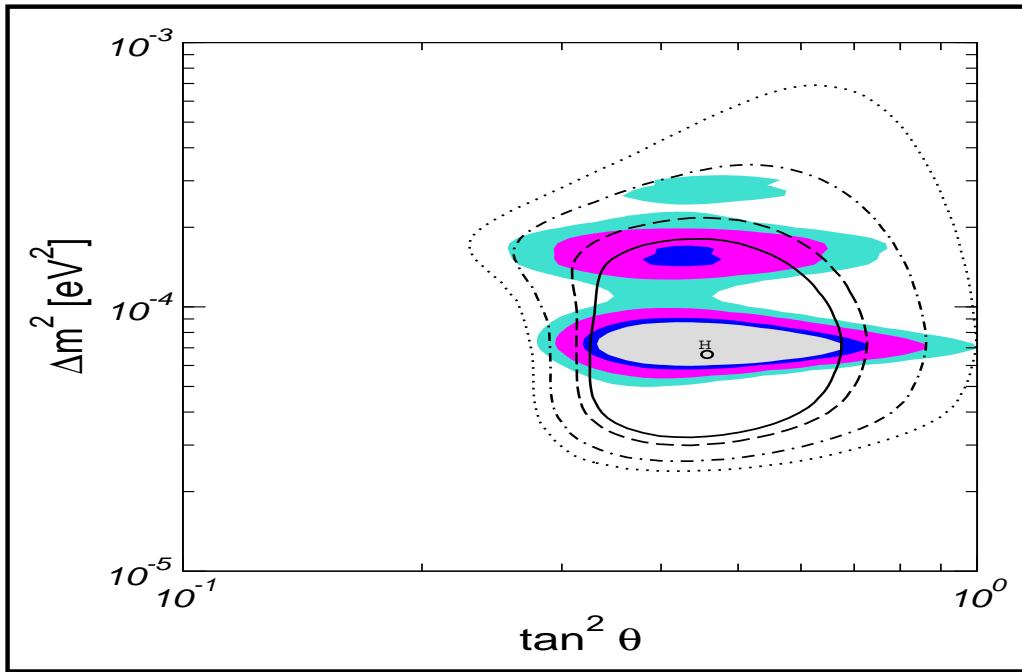
⇒ oscillations happen inside the sun!

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

$$5.1 \times 10^{-5} \text{ eV}^2 \leq \Delta m_{\text{SOL}}^2 \leq 9.7 \times 10^{-5} \text{ eV}^2,$$

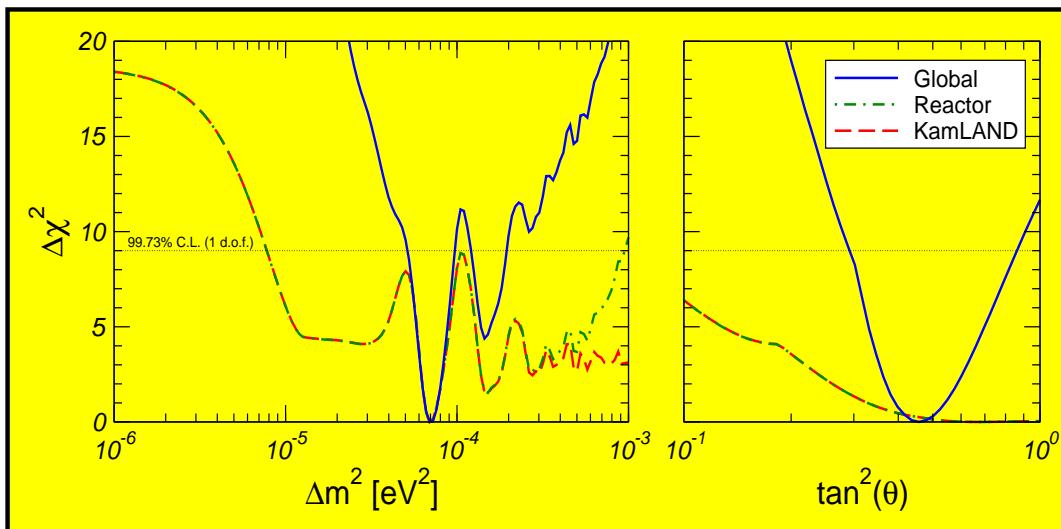
$$1.2 \times 10^{-4} \text{ eV}^2 \leq \Delta m_{\text{SOL}}^2 \leq 1.9 \times 10^{-4} \text{ eV}^2.$$

# Implications of first KamLAND results-2



Maltoni, Schwetz & Valle, hep-ph/0212129

consistency with Poisson method



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

bi-maximal models rejected

# LMA-MSW status wrt SN1987A

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

large angle 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

$E_{\bar{\nu}_e} = 14 \text{ MeV}$ ,

$E_{\text{bind}} = 3 \times 10^3 \text{ erg}$

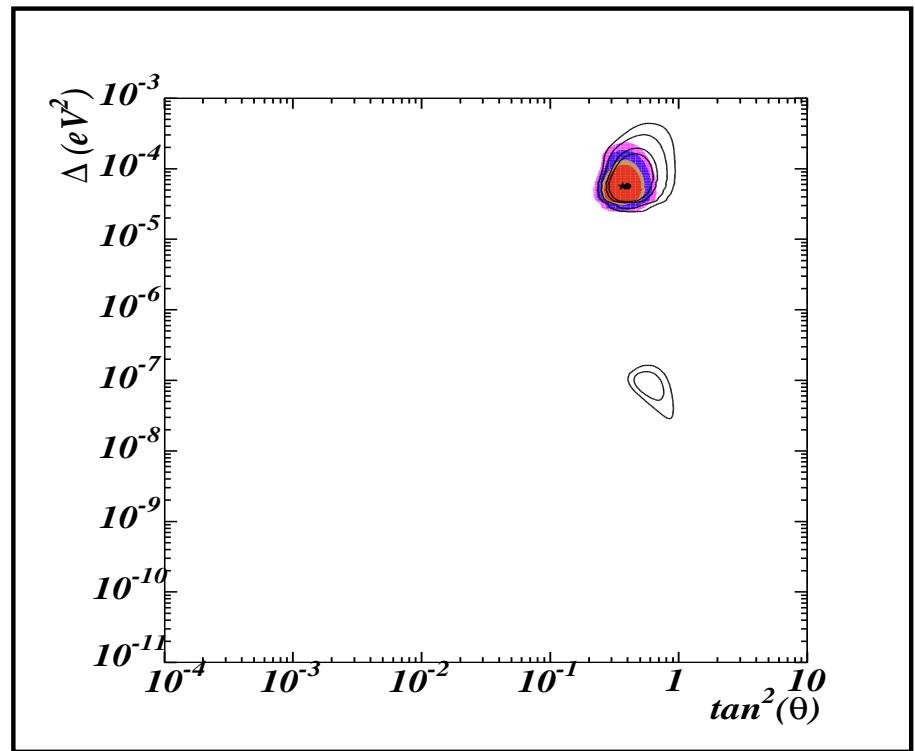
$\tau \equiv T_{\nu_h}/T_{\bar{\nu}_e} = 1.4$

pre-KamLAND

solar+SN1987A analysis

Kachelriess et al PRD65 (2002) 073016

**LMA-MSW may remain best**



# Robustness of MSW plot

Burgess et al, ApJLett, hep-ph/0209094

neutrino propagation strongly affected by noise

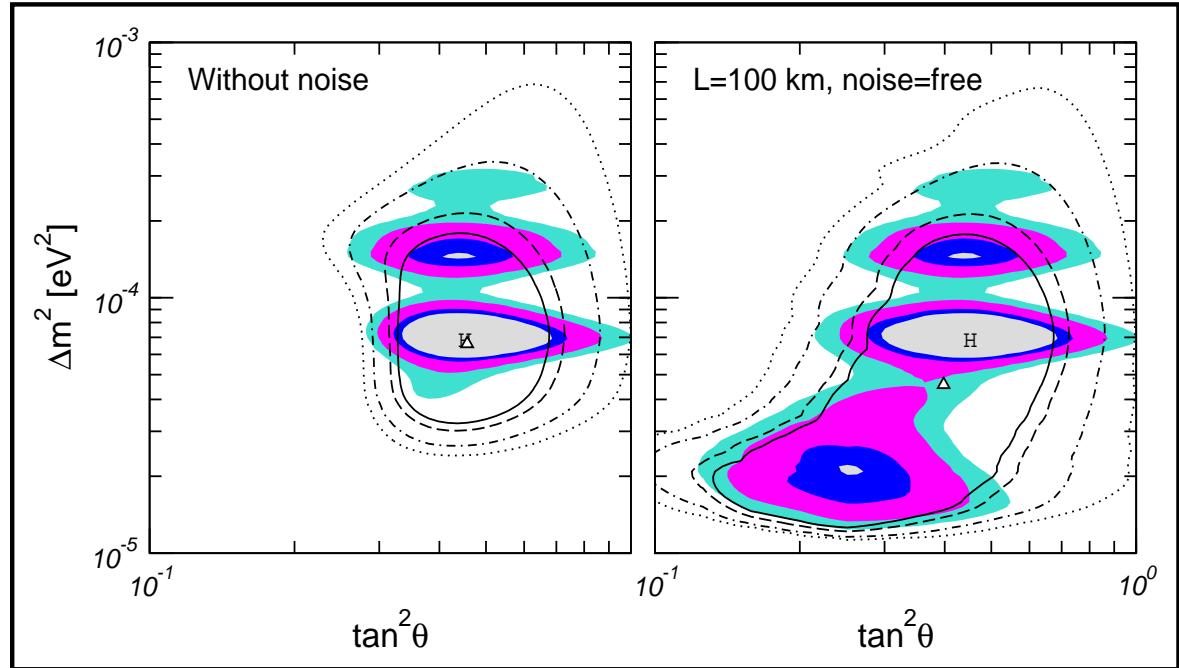
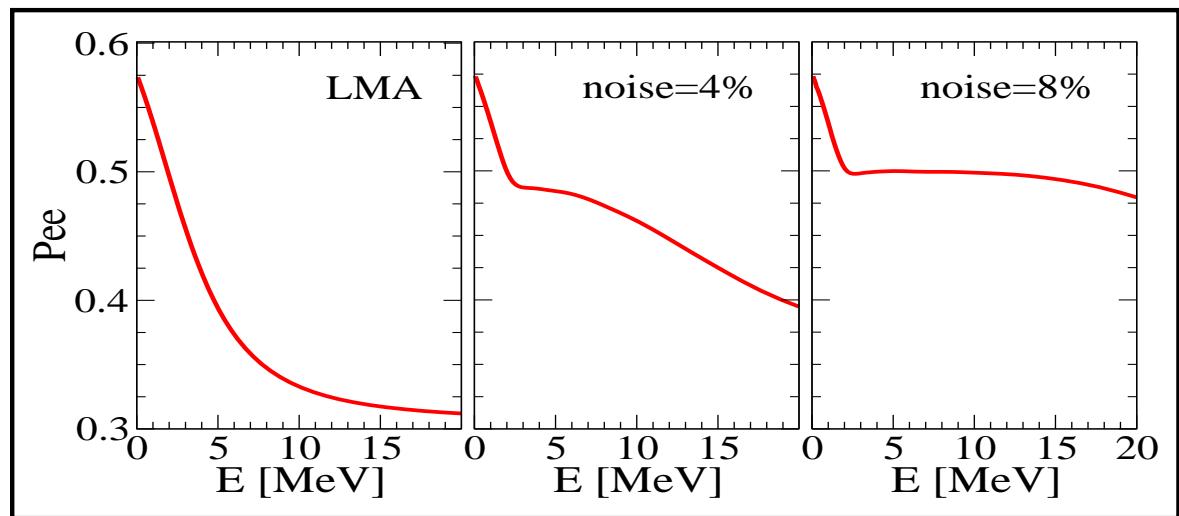
Balantekin et al 95

Nunokawa et al NPB472 (1996) 495

Burgess et al 97

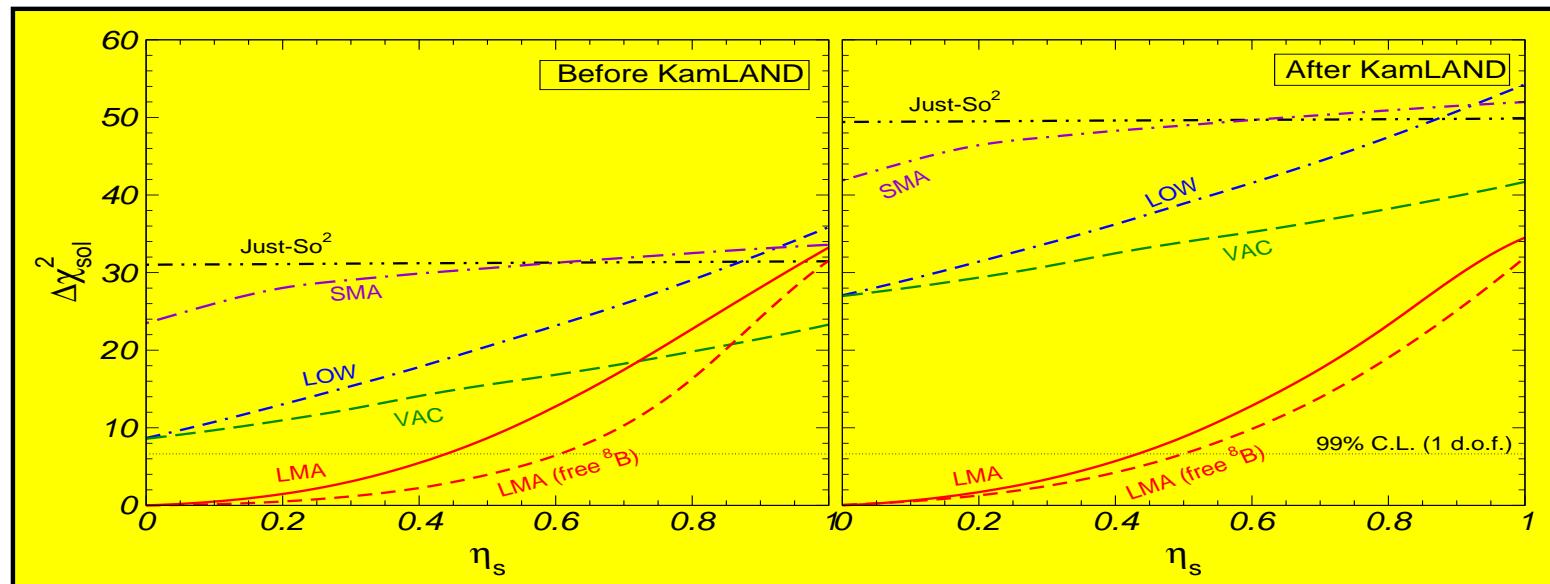
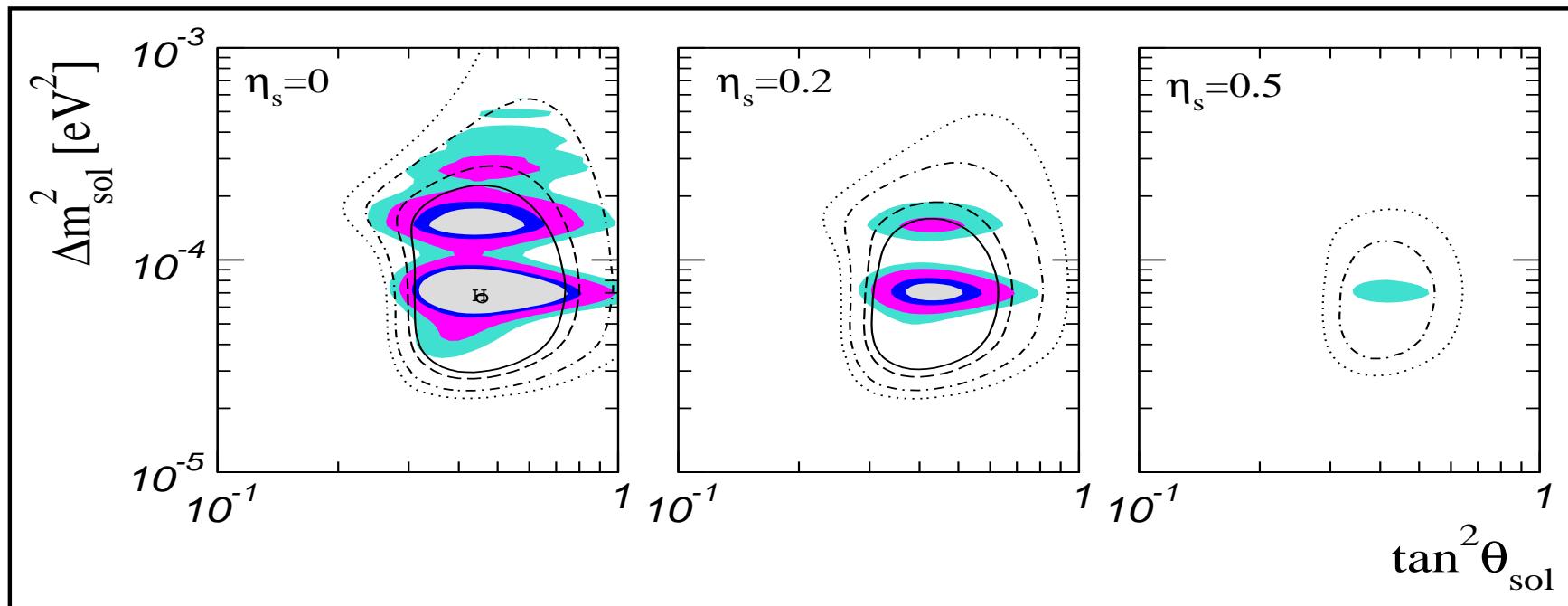
substantial distortion

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



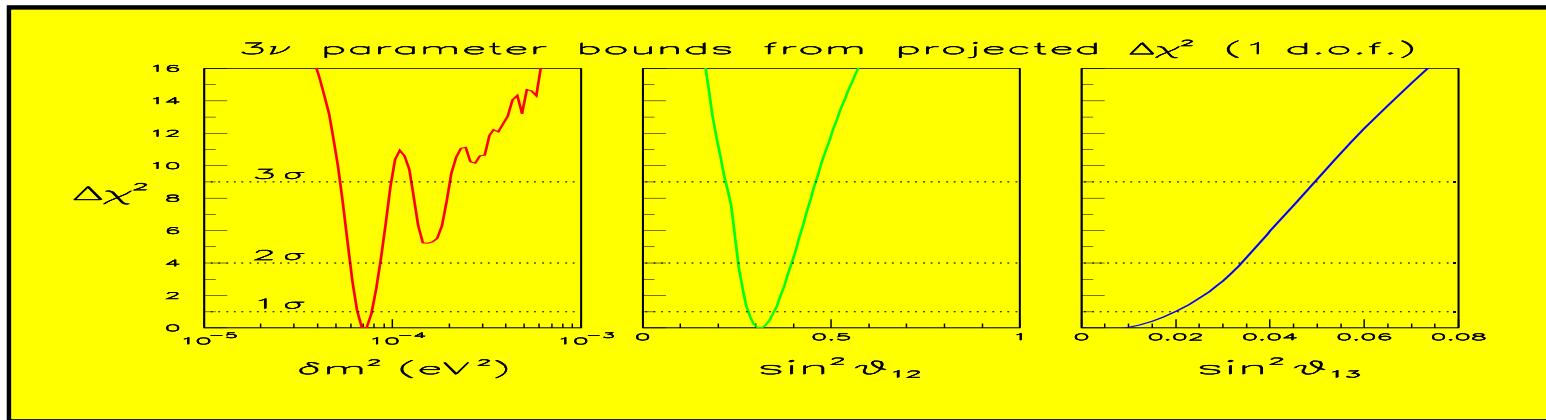
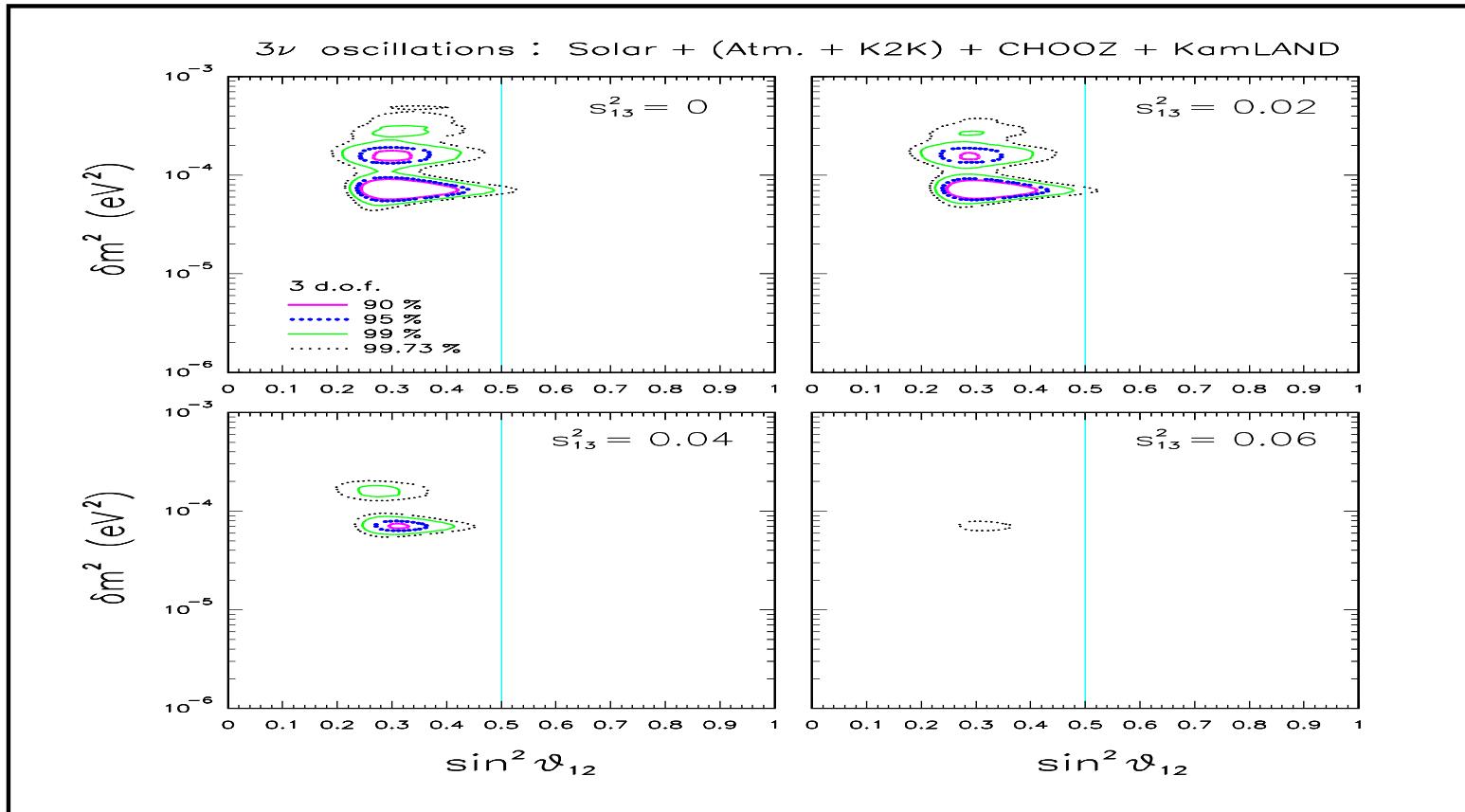
# solar+KamLAND: sterility rejection

Maltoni et al PRD **67** (2003) 013011



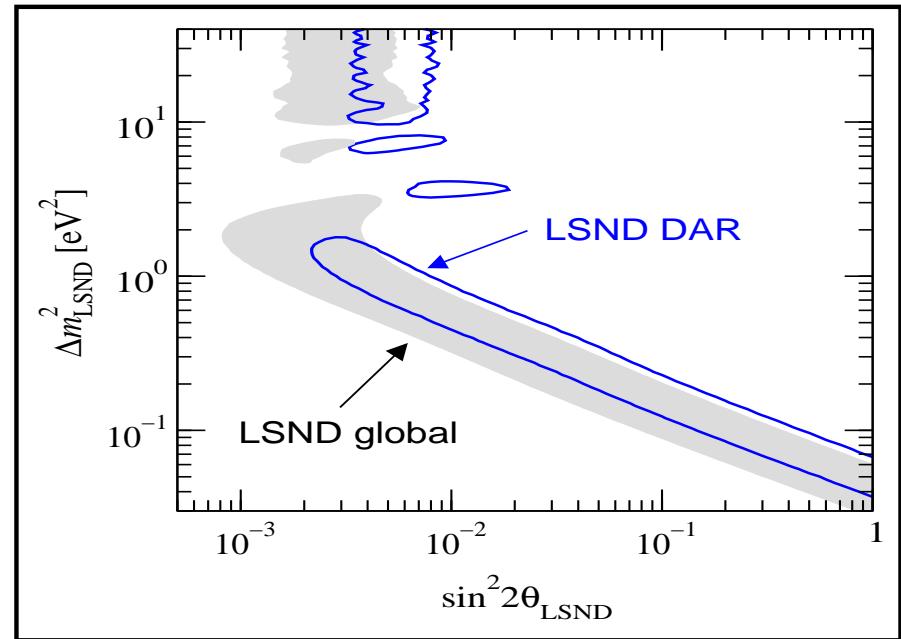
# Constraining $\theta_{13}$

Fogli, Lisi et al, hep-ph/0212127



# LSND

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



Maltoni et al, NPB **643** (2002) 321

Peltoniemi, Valle, NPB **406**, 409 (1993)

Peltoniemi, Tommasini and Valle, PLB **298** (1993) 383

Caldwell-Mohapatra PRD48 (1993) 325

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

ATM



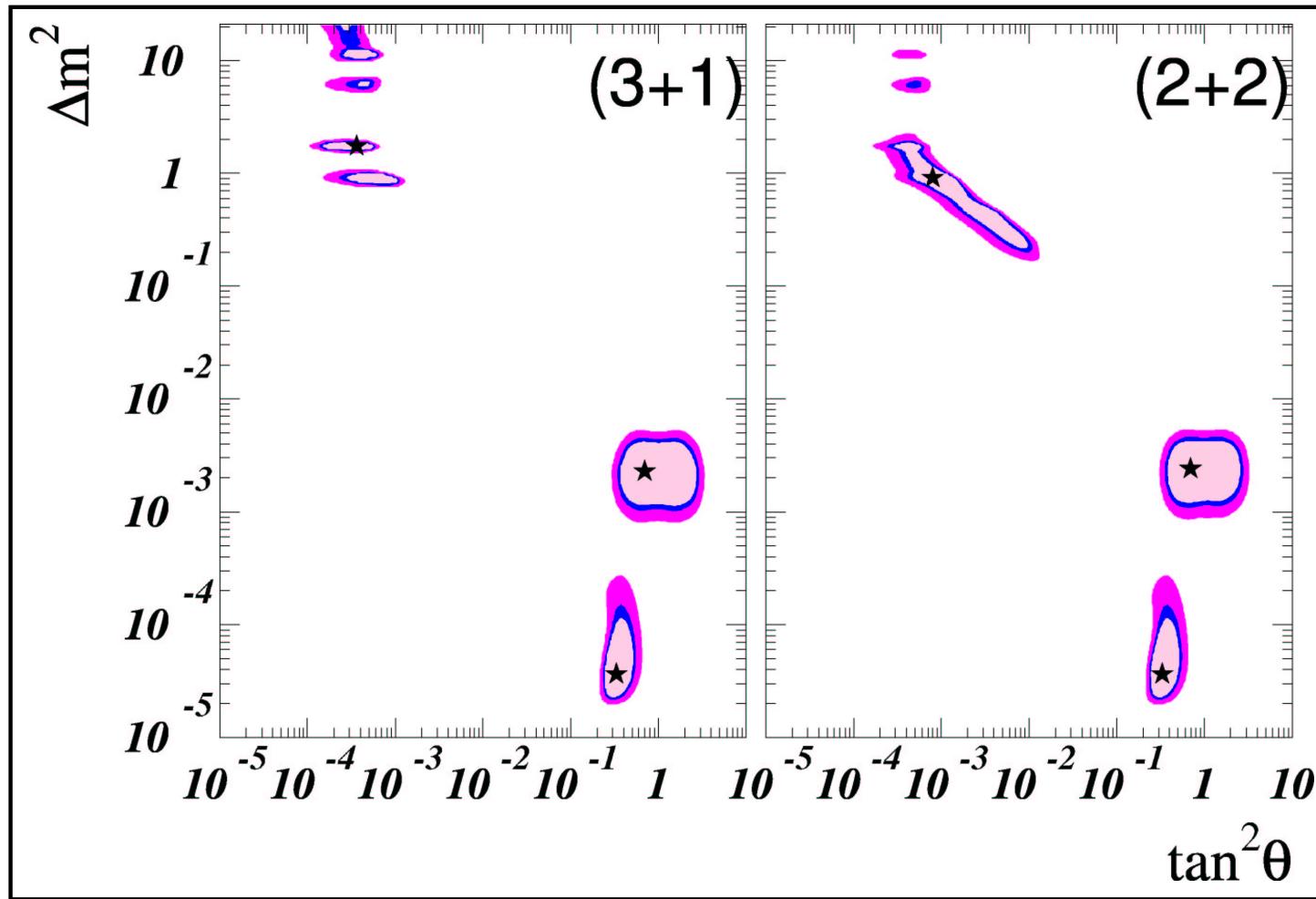
AHEP <http://ific.uv.es/~ahew>

SOL



# can one fit all current nu-data with oscillations ?

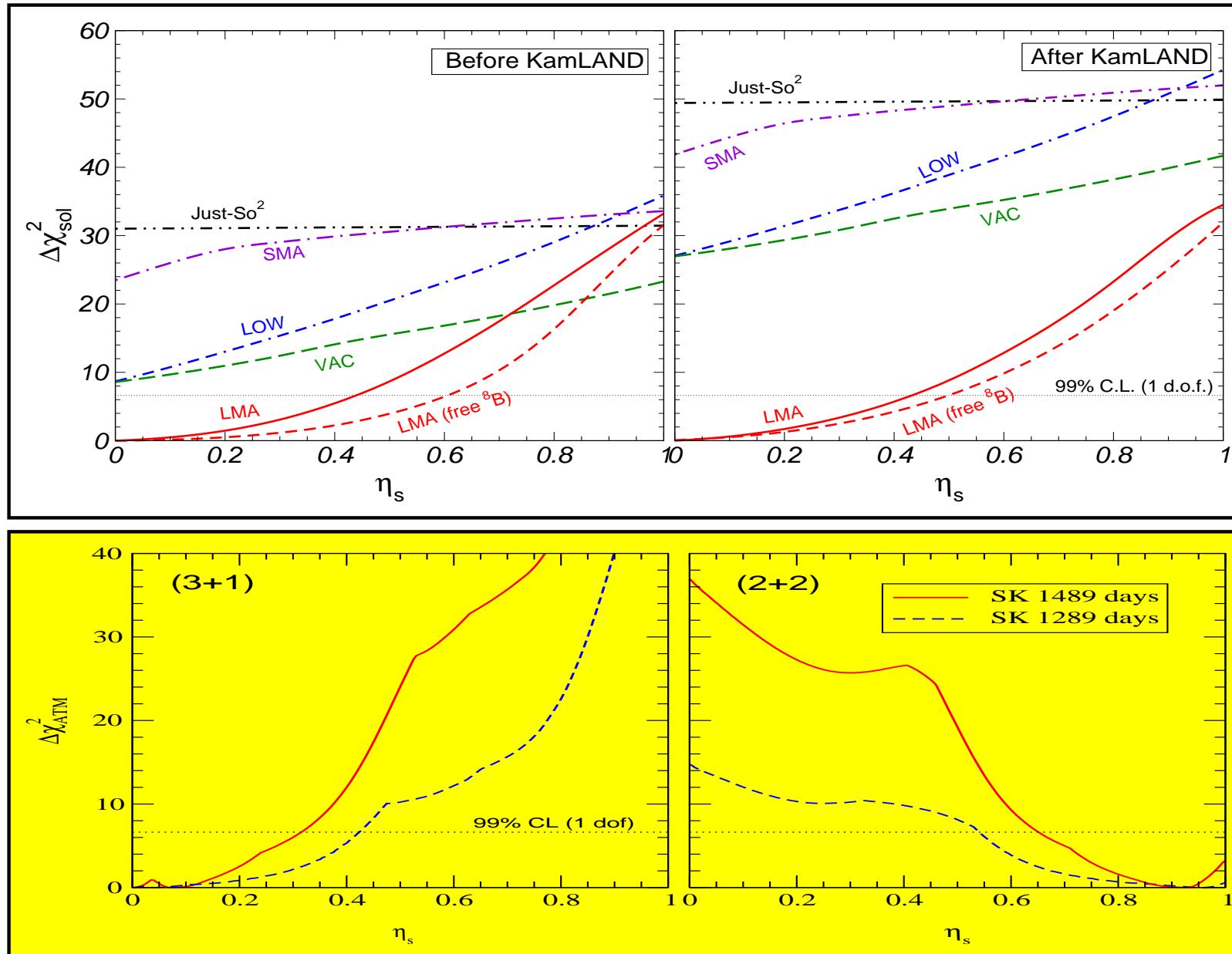
sol+atm+reac+sbl/lsnd



# stronger sterility rejection by solar & atm data

from SK-1496d-sol + SNO-NC:

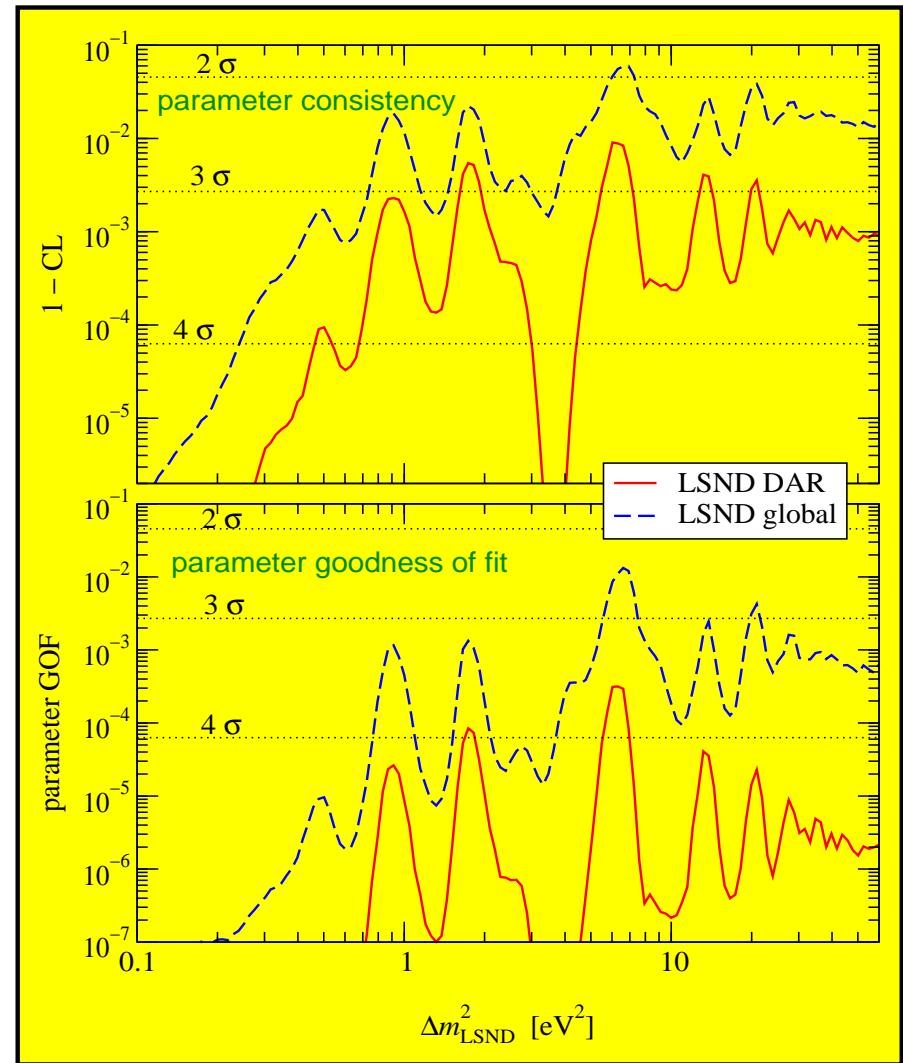
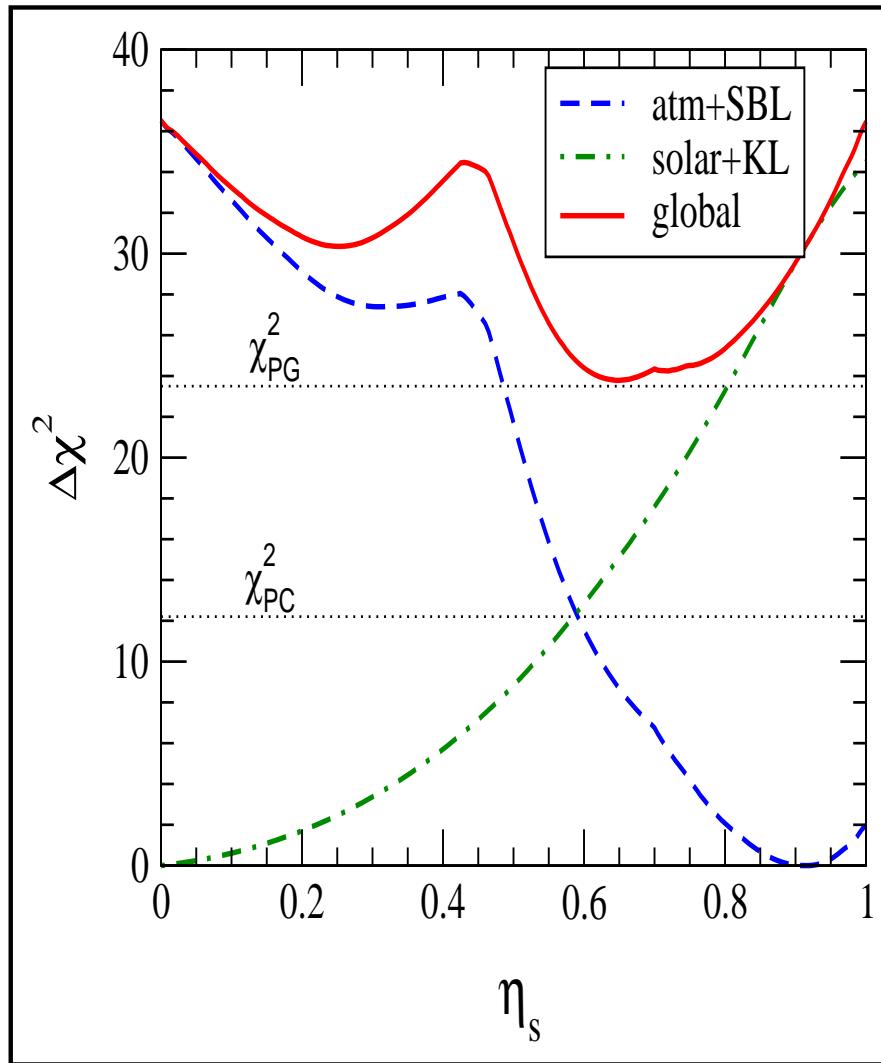
Maltoni et al PRD **67** (2003) 013011



# 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



# Absolute neutrino mass scale

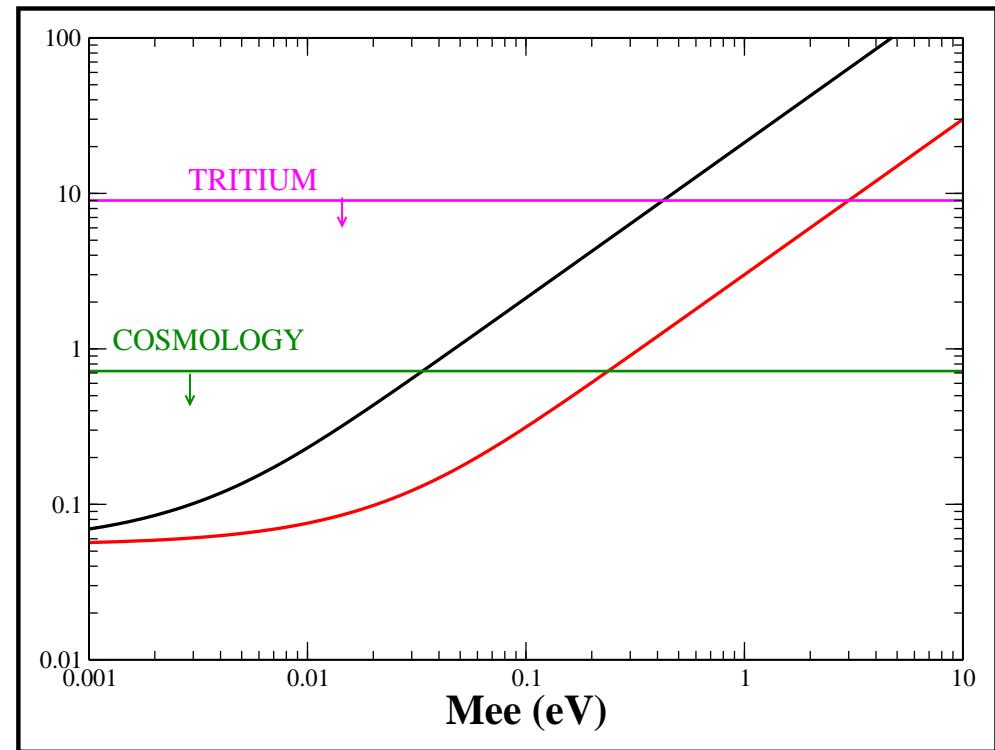
in contrast to oscillations

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 Valle, PRD **25** (1982) 2951

no such theorem for flavor violation!

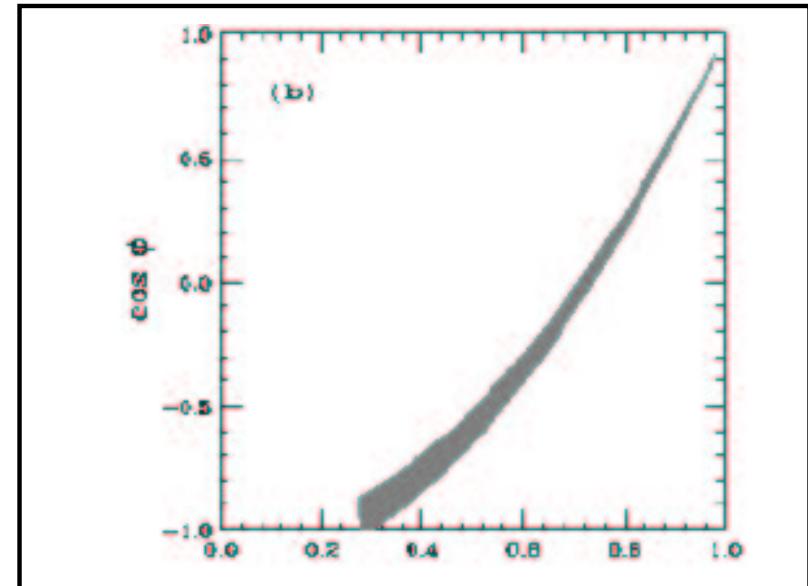
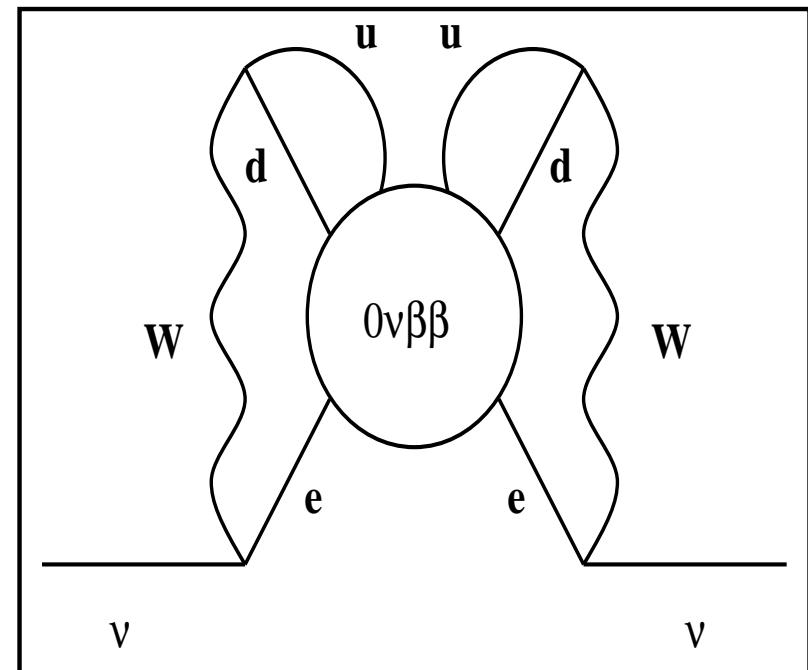
like other  $L$  violating processes  
 $\beta\beta_{0\nu}$  is sensitive to Majorana phases

Schechter and Valle, PRD **22** (1980) 2227

Wolfenstein PLB 107 (1981) 77; Doi et al

can not reconstruct majorana phases

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



# Neutrinos as astro probe

# neutrinos as deep solar probe

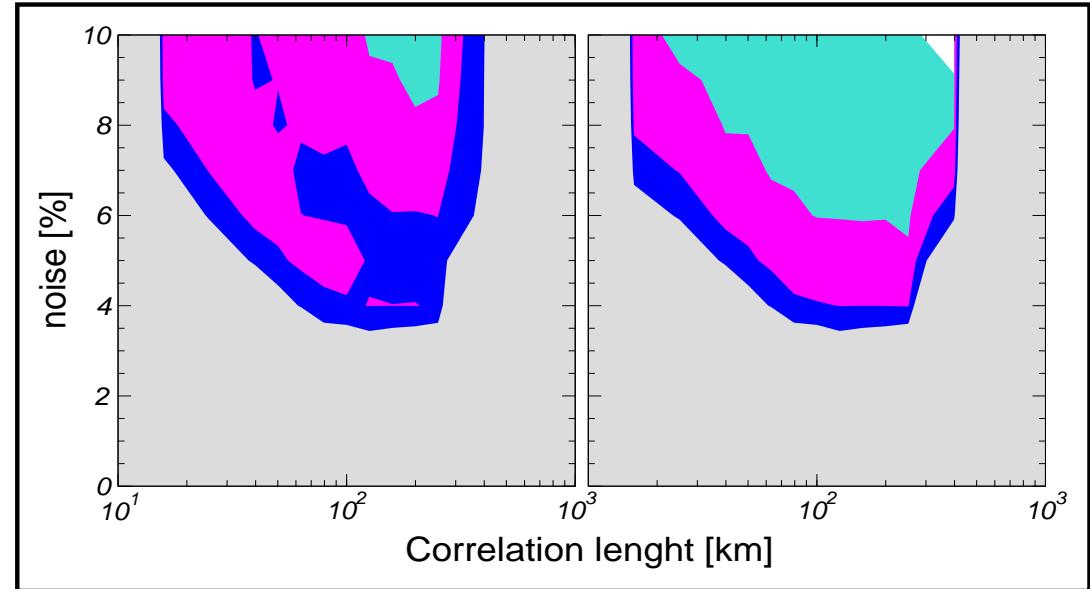
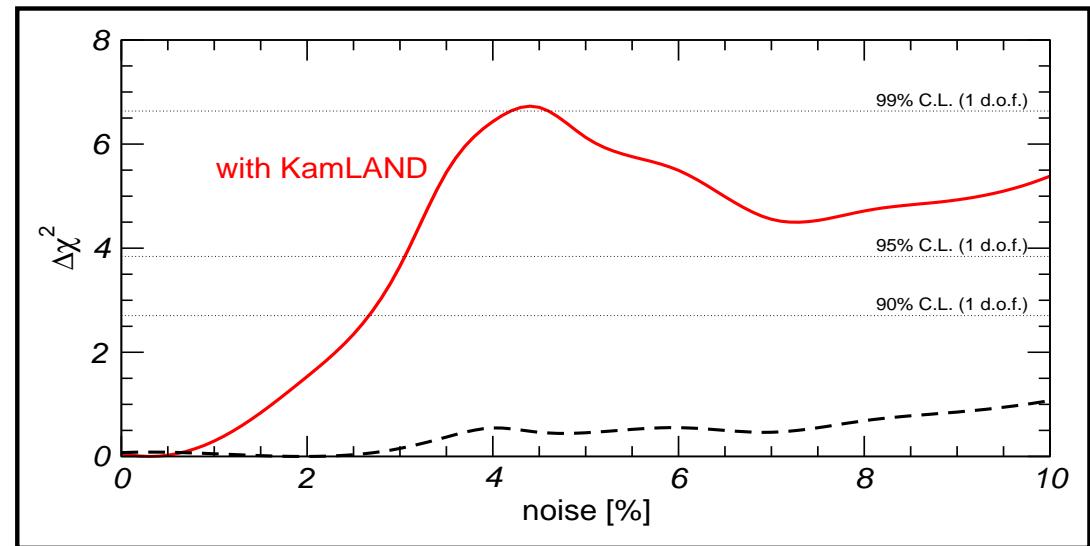
Burgess et al, ApJLet, hep-ph/0209094

$L_0 = 100\text{Km}$

**KamLAND as solar probe**

**beyond helioseismology**

free vs BFP



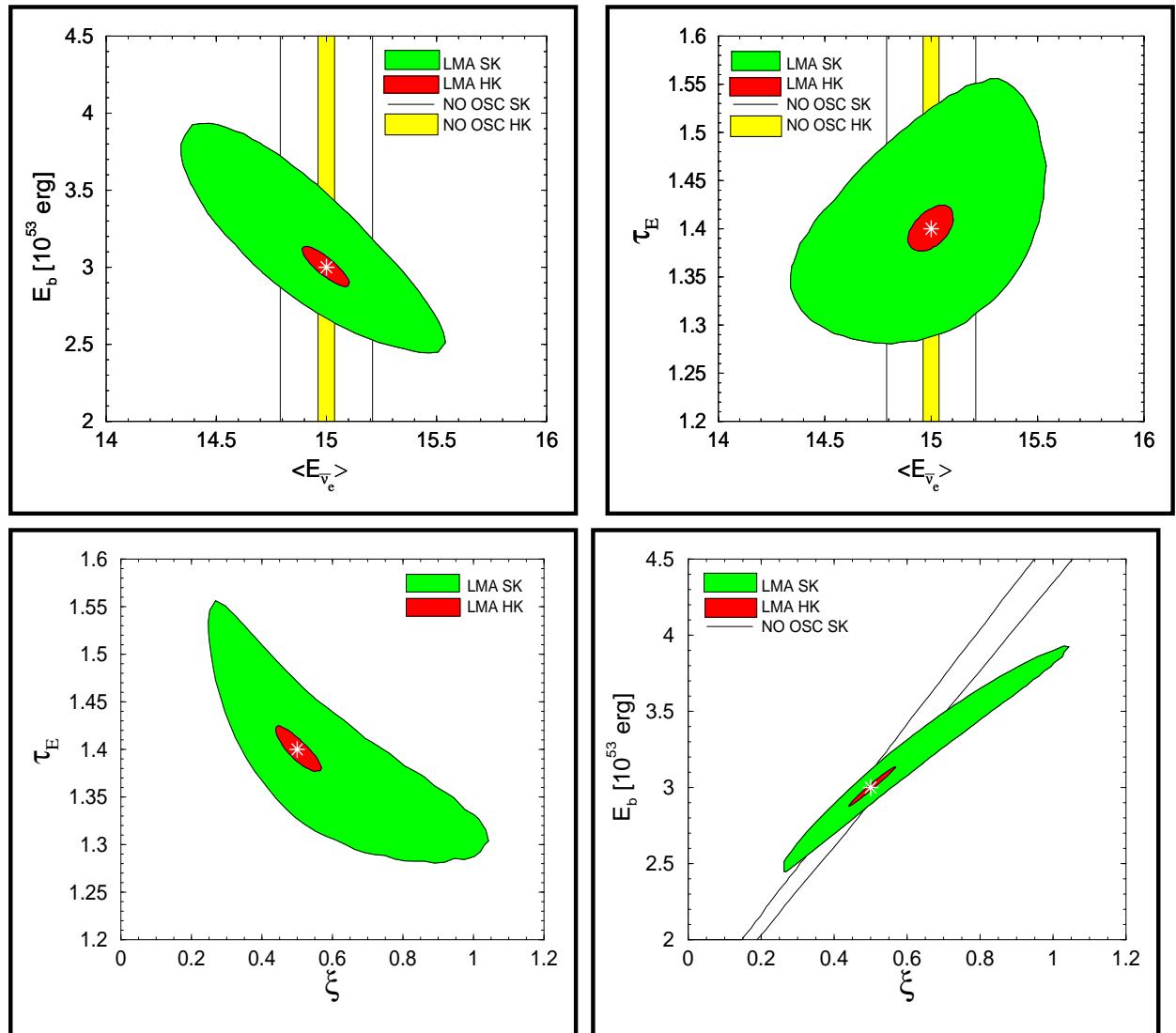
# neutrinos as future Supernova probe

Minakata et al, PLB542 (2002) 239

The measurement of a large number of neutrinos from a future galactic supernova will give us important information both on neutrino properties and on the processes that lead to the stellar explosion

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

see also Barger, Marfatia & Wood



## improved supernova parameter determination

# alternatives to oscillations?

# Oscillation vs Spin Flavor Precession

## Spin Flavor Precession

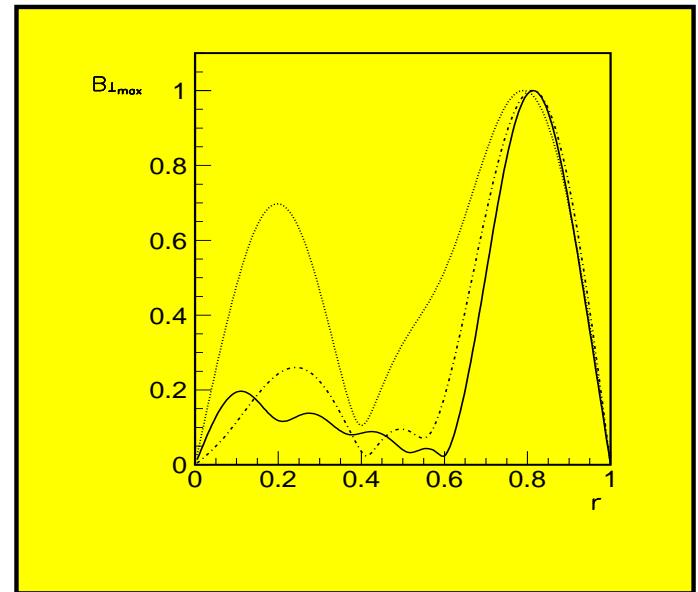
Schechter, Valle PRD24 (1981) 1883 & D25, 283

Akhmedov PLB213 (1988) 64

Lim-Marciano PRD37 (1988) 1368

MHD fixes B-profile

Miranda et al NPB595 (2001) 360, PLB521 (2001) 299



# Oscillation vs Spin Flavor Precession

Barranco et al PRD66 (2002) 093009

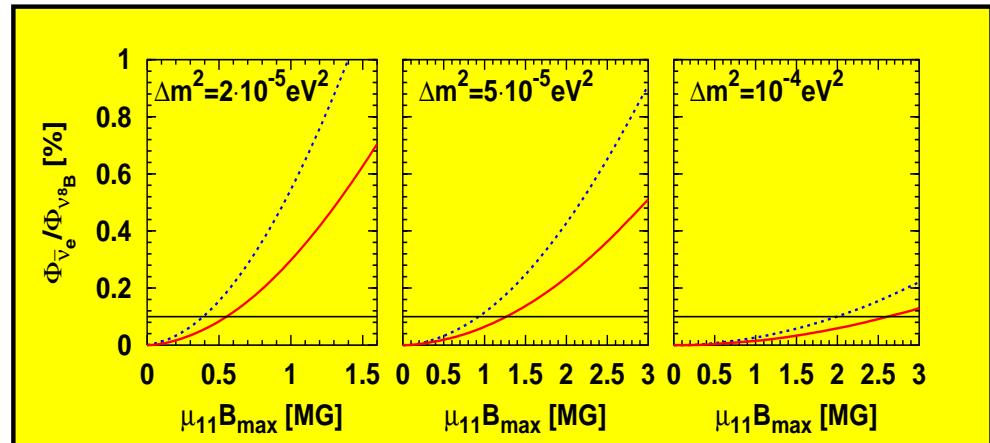
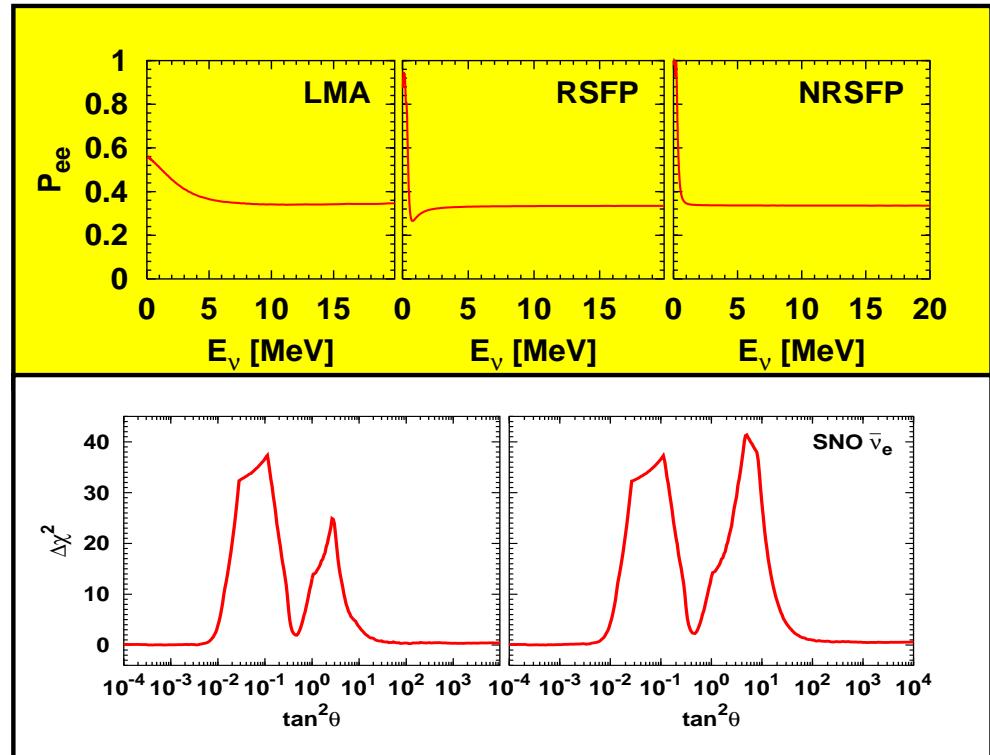
current solar data still do not allow  
the reconstruction of the profile of  
 $\nu_e$ -conversion probability

LMA-MSW, RSFP, NRSFP equivalent

KamLAND lifts degeneracy

ruling out SFP as main solution

testing SFP as sub-leading

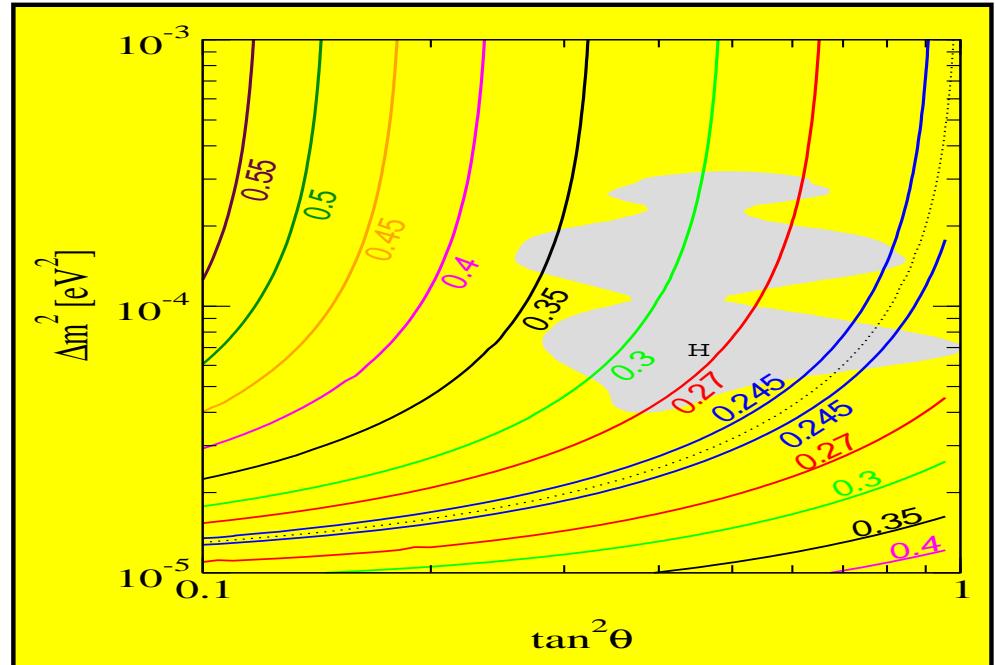
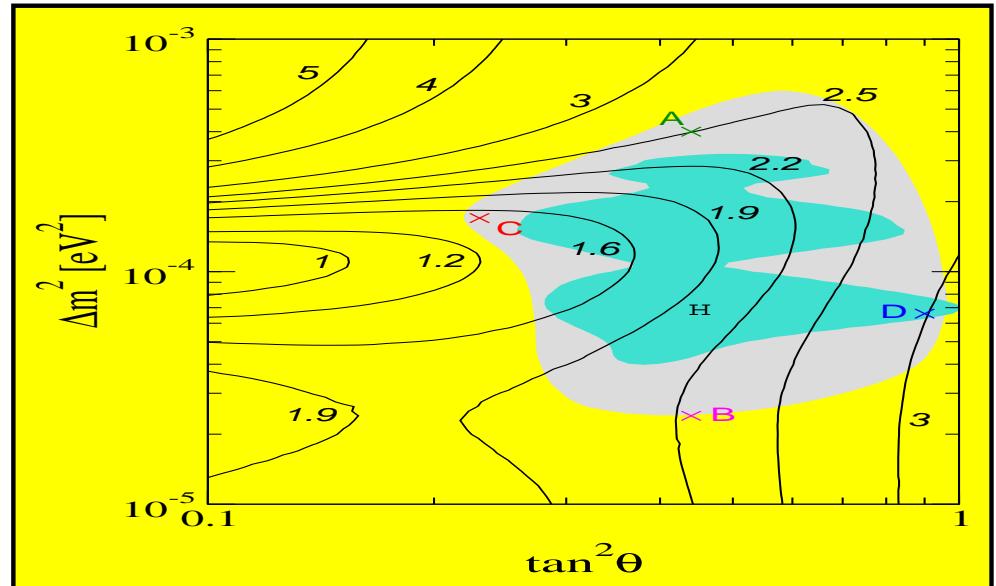


# probing neutrino magnetic moments at LMA-MSW

present sensitivity

Grimus, Maltoni, Schwetz, Tortola and Valle,  
NPB **648**, 376 (2003)

expected Borexino sensitivity



# Oscillation vs NSI

more

Non-standard interactions

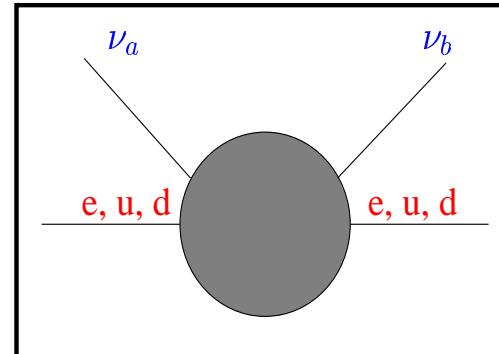
FC or NU sub-weak strength dim-6 terms  $\varepsilon G_F$

can induce oscillations of massless neutrinos in matter,  
which are E-independent, converting both neutrinos &  
anti-nu's, can be resonant in SNovae  
Valle PLB199 (1987)  
432, Roulet 91; Guzzo et al 91; Barger et al 91

excellent description of solar data

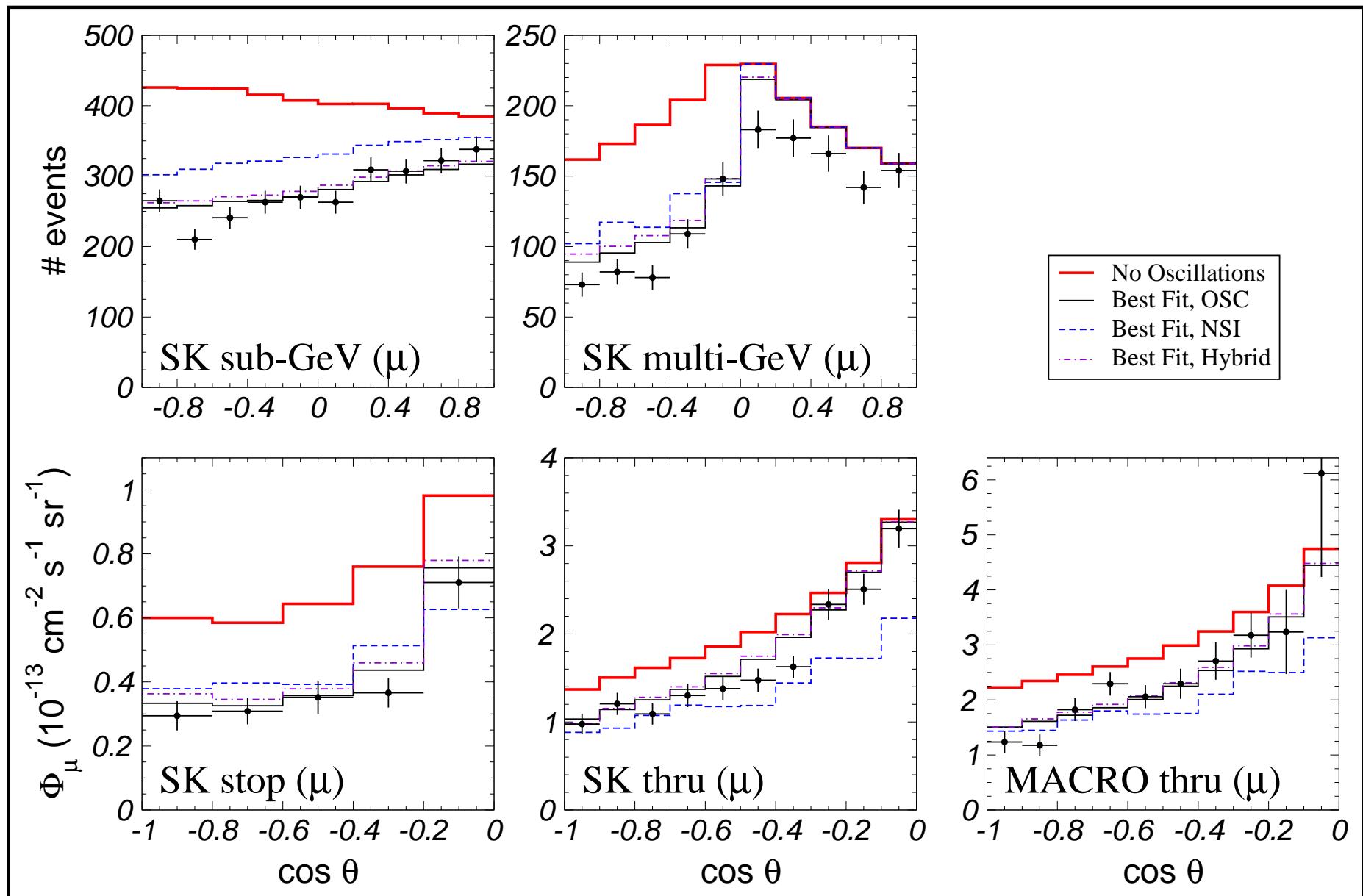
Guzzo et al NPB629 (2002) 479

KamLAND implies not the leading mechanism



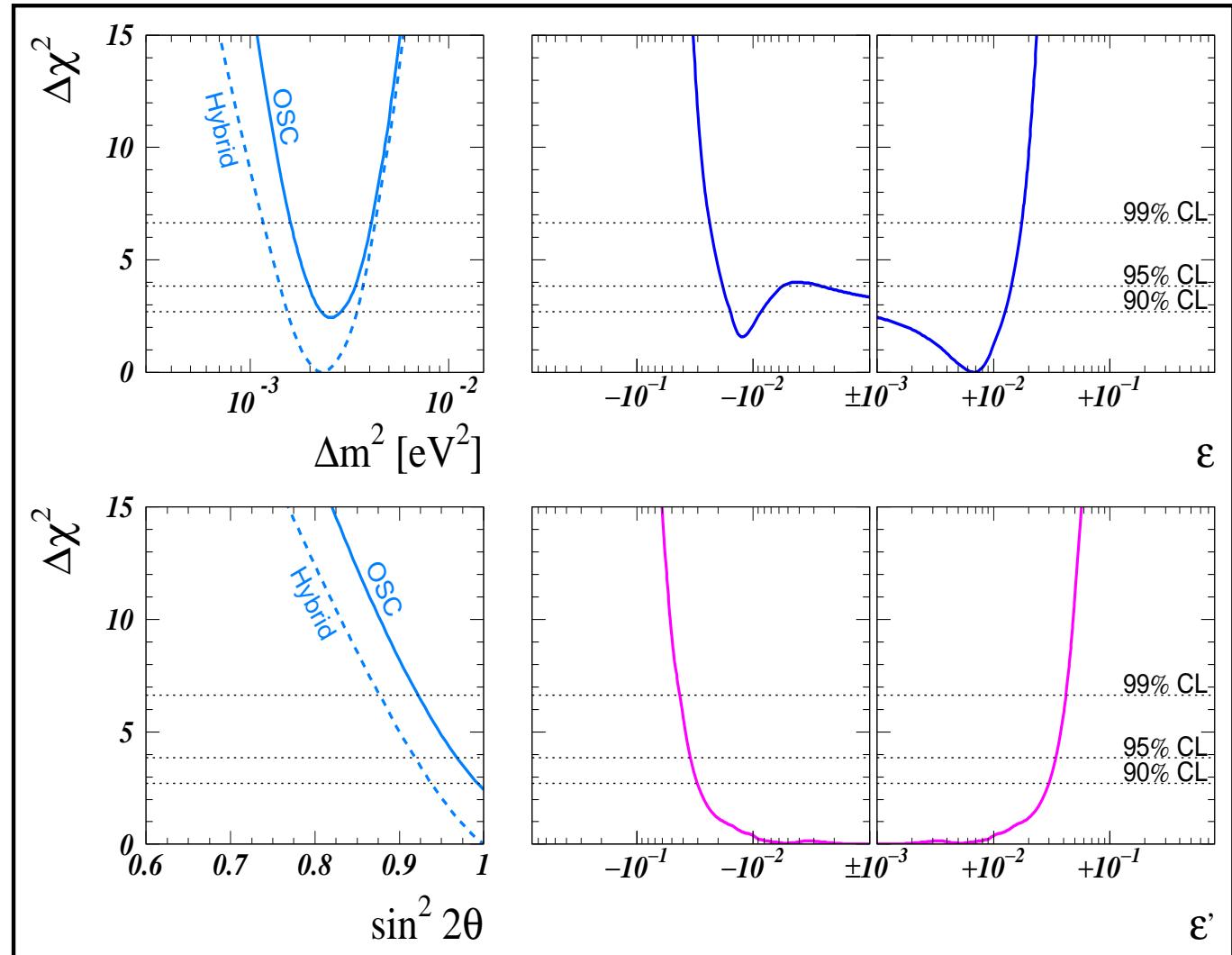
# How robust are atmospheric oscillations?

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



# probing NSI with atmospheric data

Fornengo et al,  
PRD **65** (2002) 013010

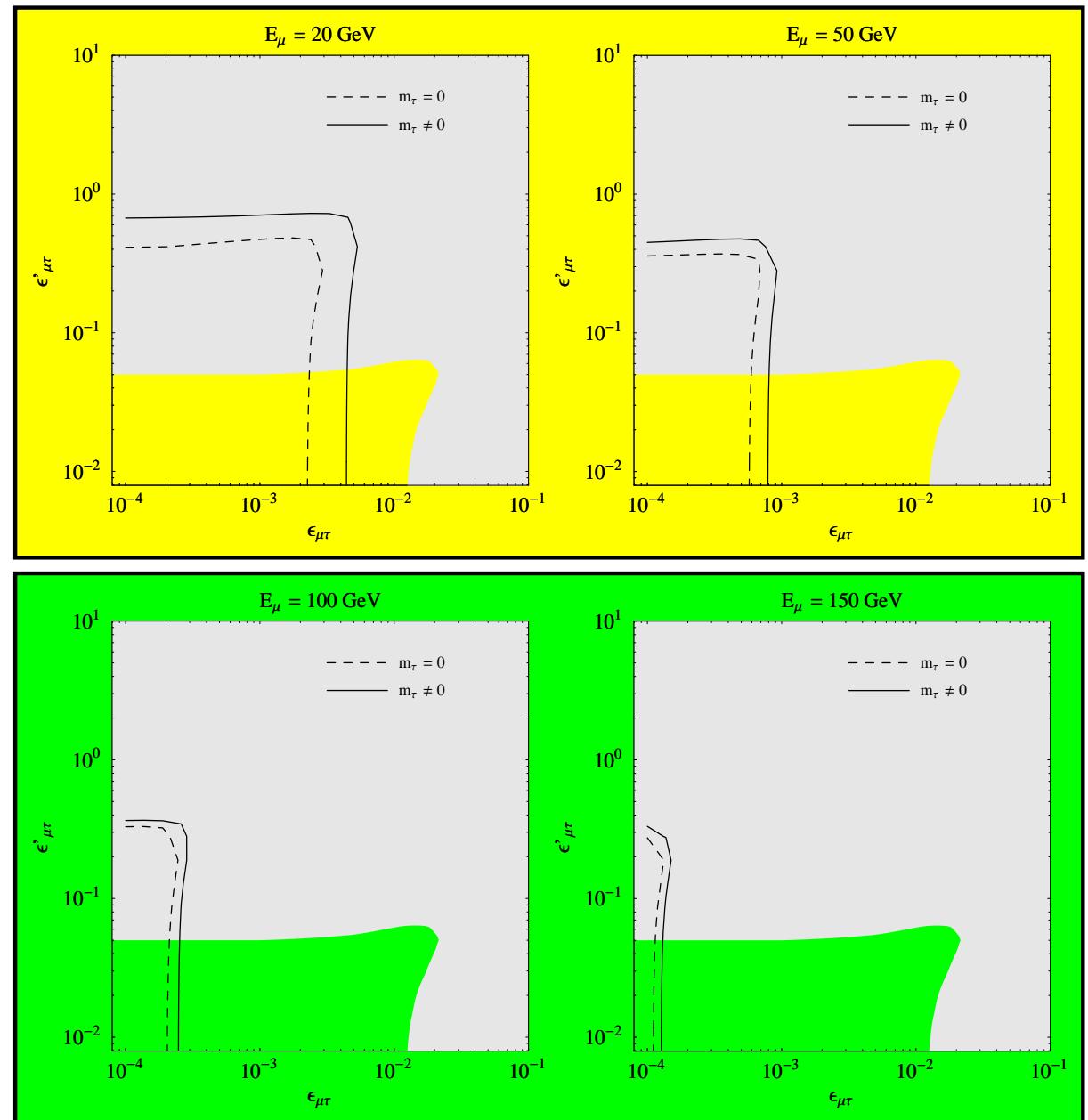


atm bounds on FC and NU nu-interactions

# Improved FC-tests at NuFact

Huber & JV PLB 523 (2001) 151

10 kt detector, 0.33  $\nu_\tau$  detection  
eff above 4 GeV; need no tau  
charge id



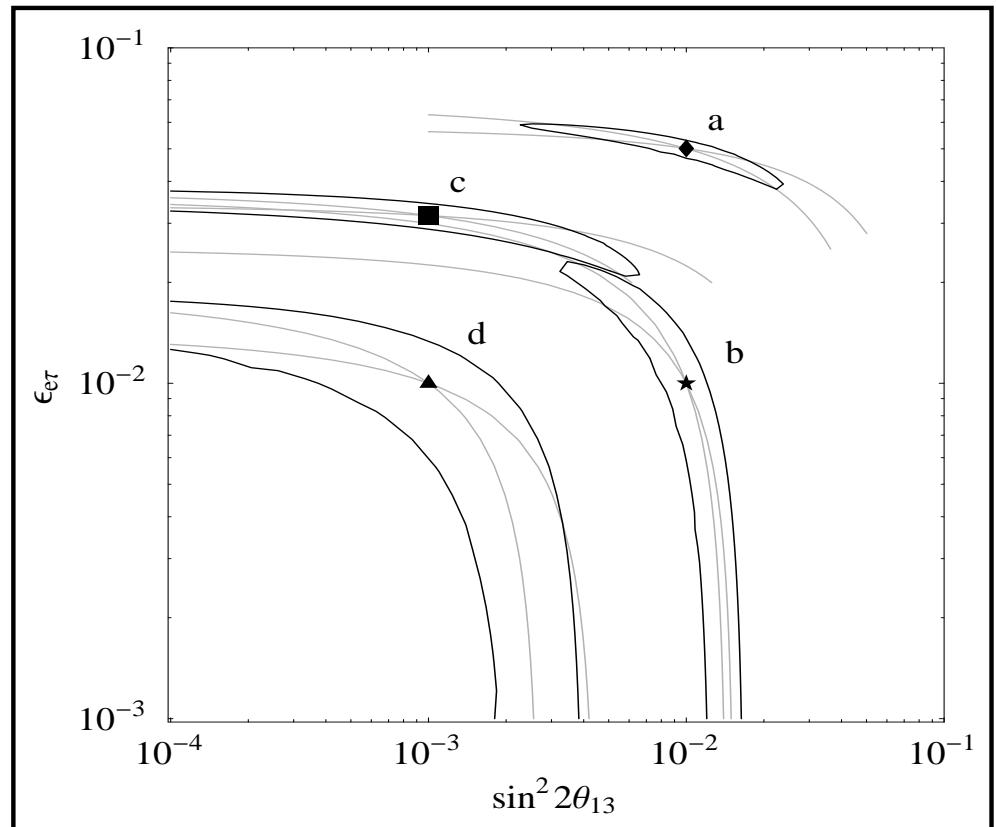
# FCI-oscillation confusion theorem

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

Huber, Schwetz & JV PRL **88** (2002) 101804

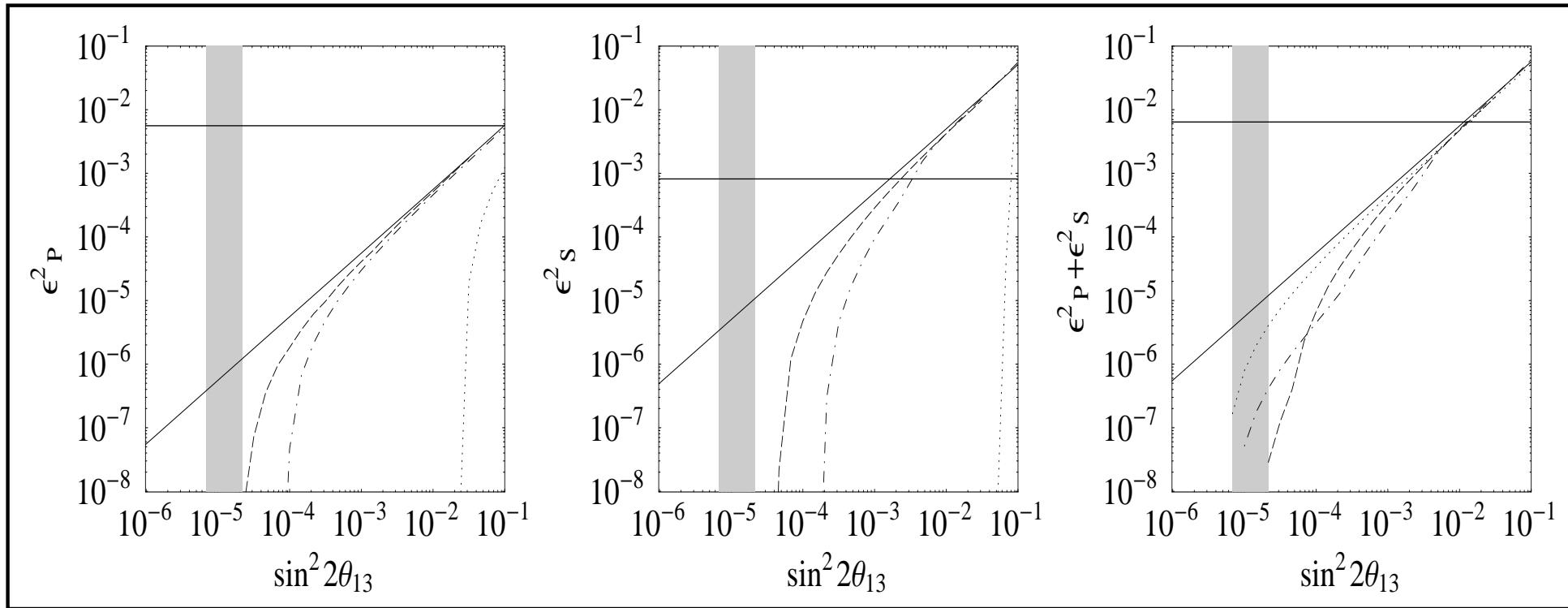
near-site programme essential

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



# FCI-oscillation confusion theorem-2

Huber, Schwetz and J. V. PRD **66**, 013006 (2002)



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

90% CL reach on  $\sin^2 2\theta_{13}$  vs NSI bounds

The dotted line is for 700 km, dash-dotted for 3 000 km and dashed is for 7 000 km baseline

horizontal black line is the current NSI limit

vertical grey band is the sensitivity without NSI

diagonal solid line is the theoretical bound derived from our confusion theorem

# Theory of neutrino properties

how to reconstruct the parameters

how to reconstruct the underlying Theory

# simplest gauge theory mixing matrix

- 3 angles  $\theta_{ij}$

23=atm    12=sol    13=reac

- 1 KM-like

$\phi$

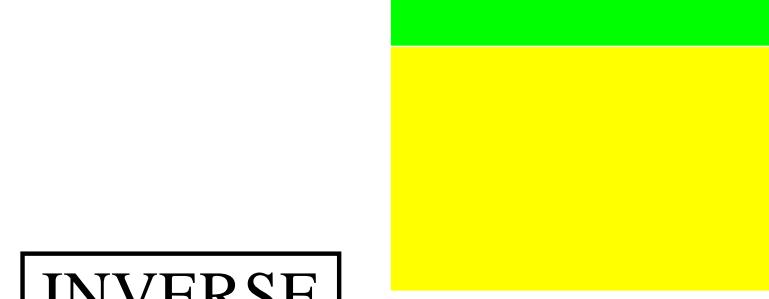
- 2 Majorana phases

$\beta\beta_{0\nu}$

$\phi_1, \phi_2$

- max  $\theta_{23}$ , large  $\theta_{12}$  & small  $\theta_{13}$

hierarchical splittings



quasi-degenerate

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

Ioannissian & J. V. PL B332 (1994) 93; Caldwell & Mohapatra; Joshipura; Bamert & Burgess;  
Balaji, Mohapatra, Parida & Paschos, Babu, Ma & Valle, ...  
Ellis & Lola, Ma, Casas et al, Haba et al, ... back

# leptonic CP violation

- will be a challenge !

“Dirac” CPV suppressed, since  $\phi$  disappears when  $\Delta_{12} \rightarrow 0$

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

- “Majorana” CPV absent from conventional  $\Delta L = 0$  oscillations, Bilenky et al

but present in  $\Delta L = 2$  oscillations

Schechter and Valle, PRD **23** (1981) 1666

- V-A suppression also present in  $\beta\beta_{0\nu}$

Doi et al 1981, Wolfenstein

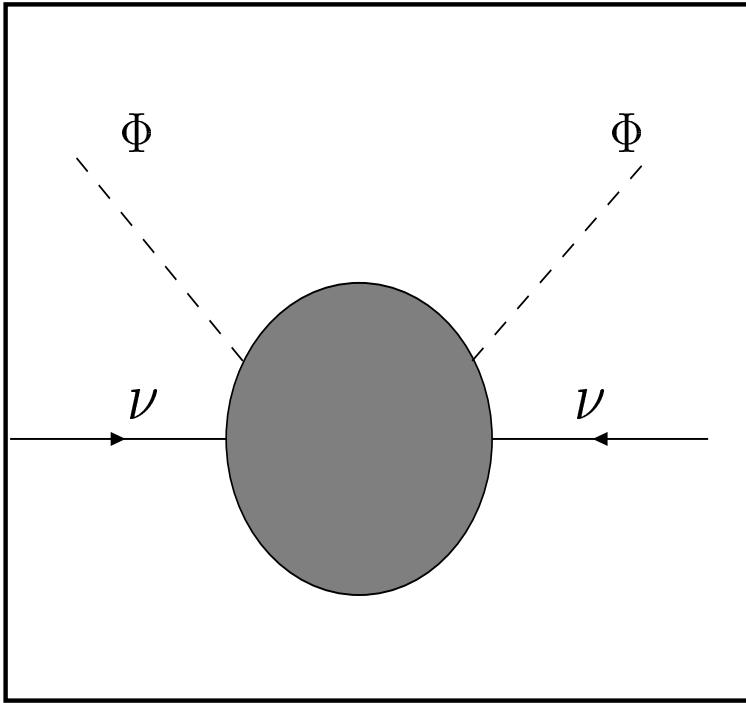
- but absent when large “Majorana”-masses are involved, such as **leptogenesis**

- **REMARKABLE SEESAW CONNECTION**

Silvia Pascoli’s talk

# Theory ideas

# basic dim-5 operator back



- from Gravity

- from seesaw schemes

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

Weinberg; Barbieri, Ellis, Gaillard; Zee & Weldon

# old but unfamiliar seesaw features

Schechter, Valle, PRD **22**, 2227 (1980) & D **25**, 774 (1982)

- scale need not be high since number of  $SU(2) \otimes U(1)$  singlets is arbitrary
- far more angles and phases in lepton mixing than needed to describe quarks:
  - (i) Majorana mass terms are not invariant under rephasings
  - (ii) the isodoublet neutrinos mix with the isosinglets
- doublet-singlet mixing implies a rectangular lepton mixing matrix  $K$  which may be decomposed as  $K = (K_L, K_H)$ , where  $K_L$  and  $K_H$  are non-unitary
- explicit parametrization in terms of  $\theta_{ij}$  and CP violating phases  $\phi_{ij}$
- non-trivial matrix  $\nu_i \nu_j Z$  vertex, described by  $P = K^\dagger K$
- charged and neutral currents may produce sizeable NSI
- The (3, 1) model has 2 massless neutrinos
- basis for hybrid model with tree-induced atm and loop-induced solar

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

# predicting nu-mass and mixing?

back

- 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

## In short

- oscillations fit well sol+atm, but **not LSND**
- LMA-MSW as astro-probe: SuperNovae and Sun  
probing the Sun beyond helioseismology
- **non-standard properties can only play a sub-leading role in solar and atm robustness**
- NSI test @ NuFact    e-tau NSI-OSC confusion...
- **no hard theory predictions**    **but suggests Majorana**
- if neutrino masses arise from low energy supersymmetry, neutrino properties may be testable at high energy accelerators