“Neutrino properties before and after KamLAND”

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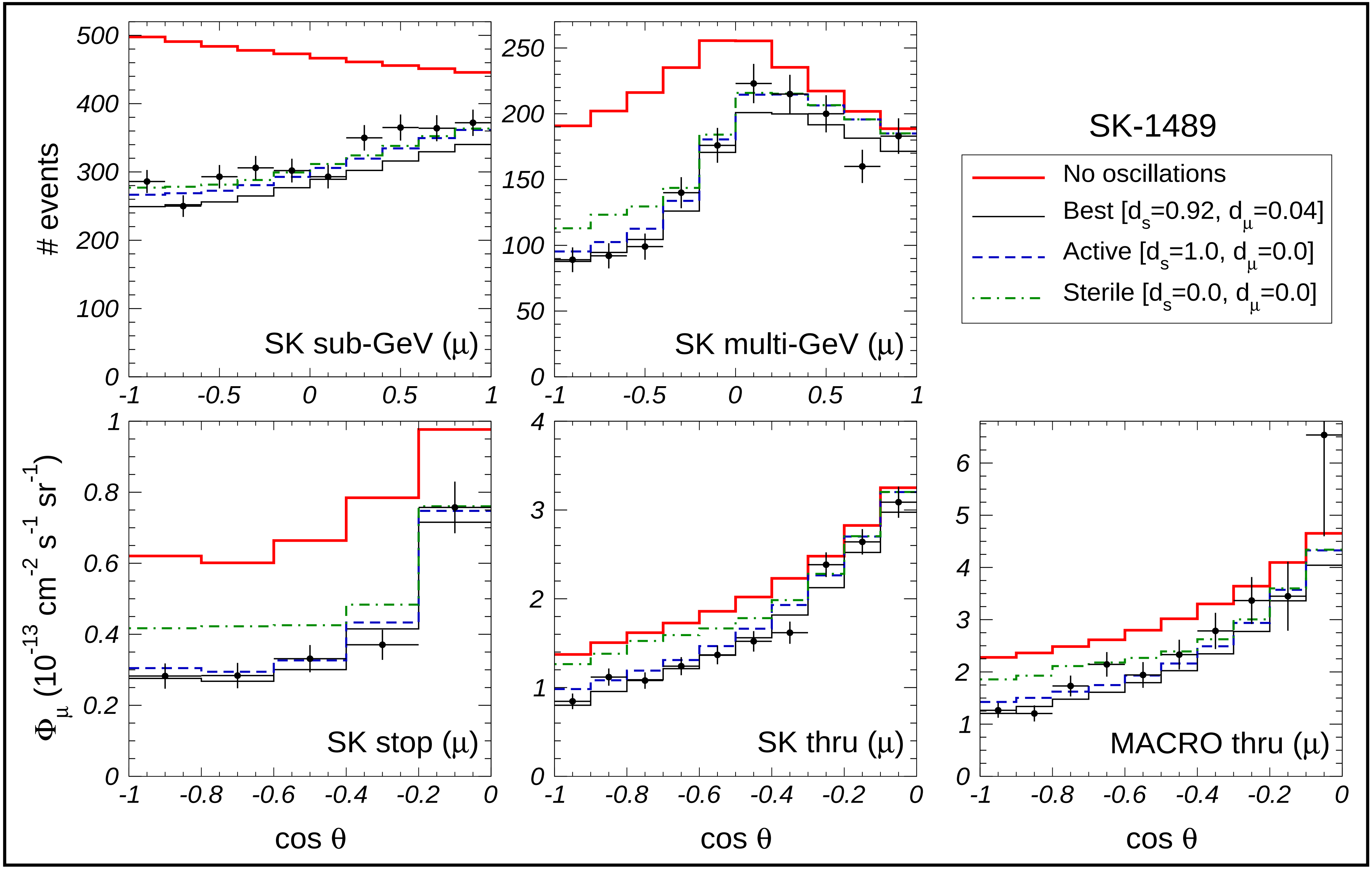
Talk in honor of Joe Schechter, on the occasion of his 65th birthday

Based on review

S. Pakvasa and JV hep-ph/0301061

Atmospheric zenith distribution

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



atmospheric neutrinos

1289 vs 1489-day samples

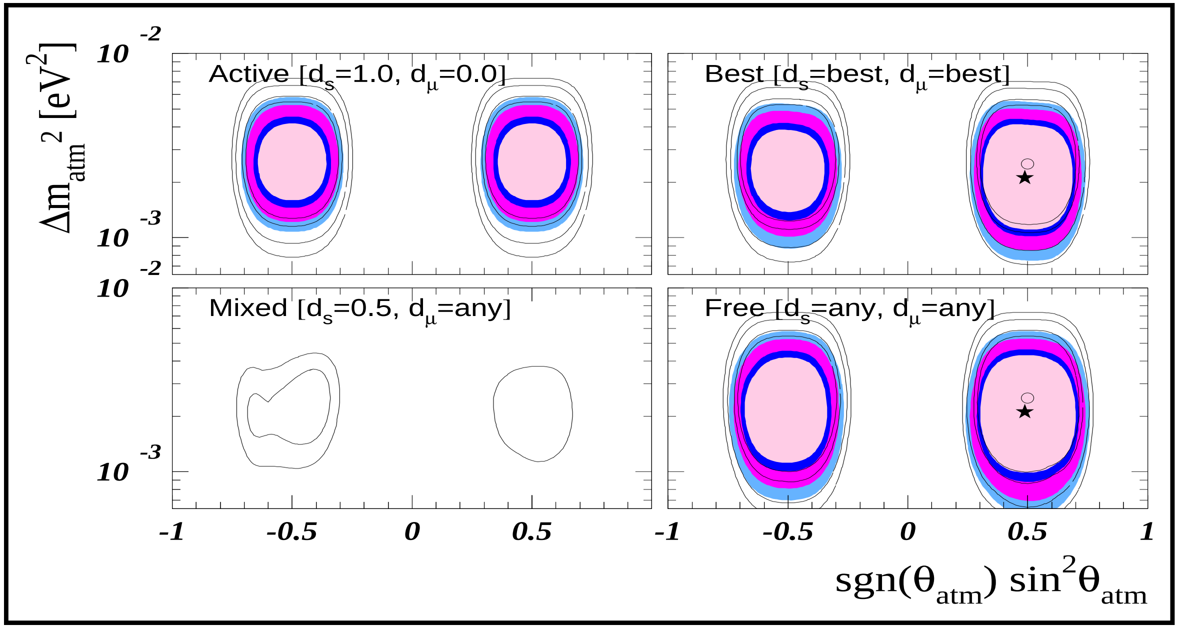
from Maltoni et al

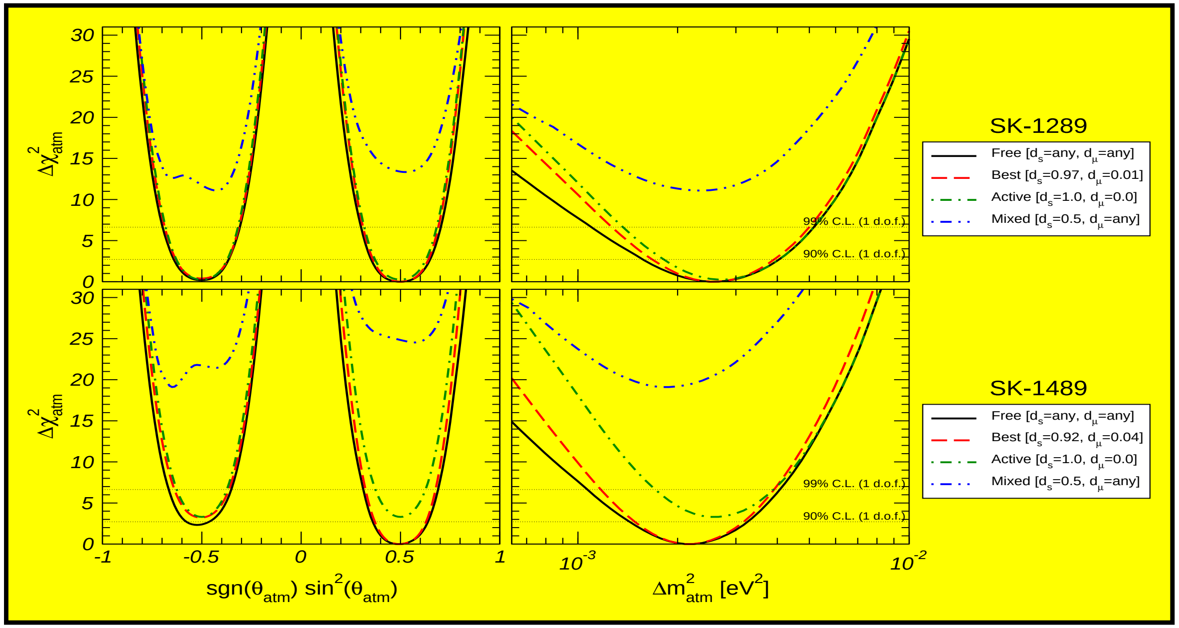
PRD **67** (2003) 013011

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

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

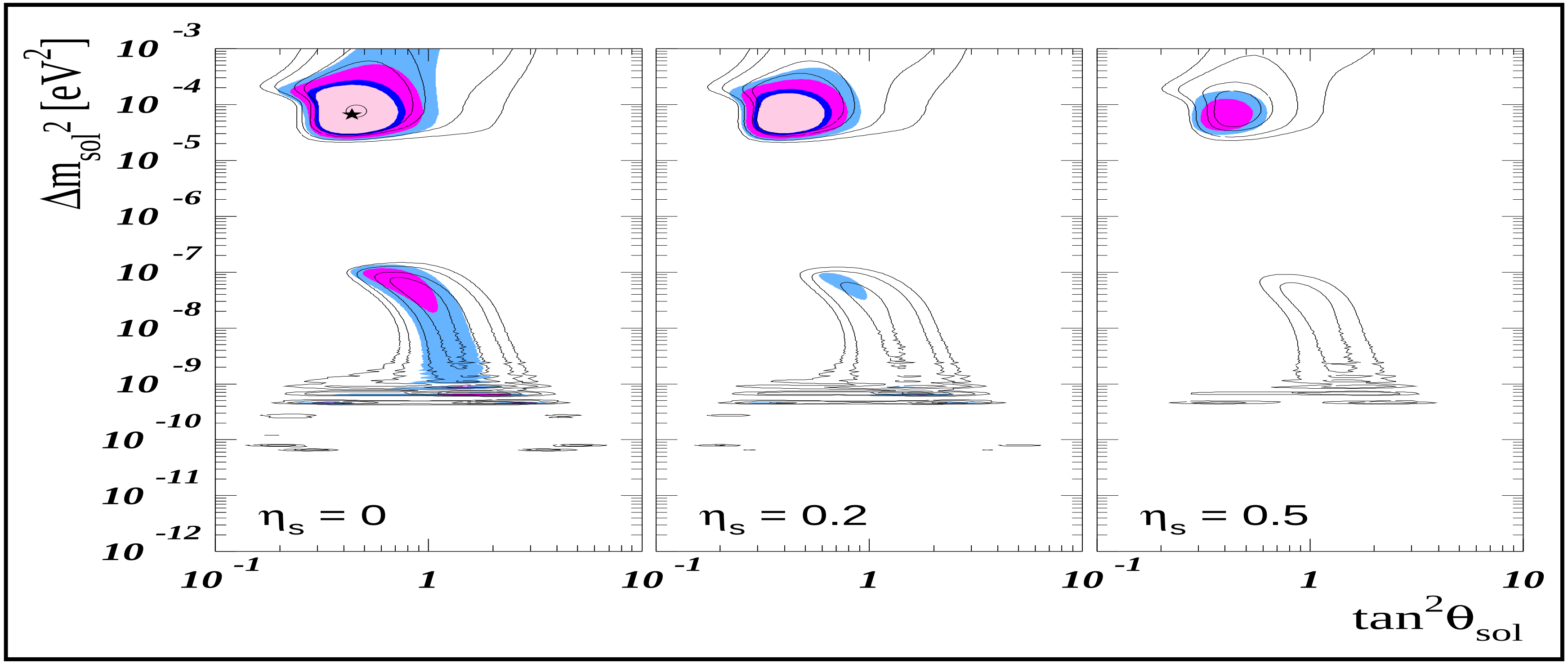
higher sterility rejection

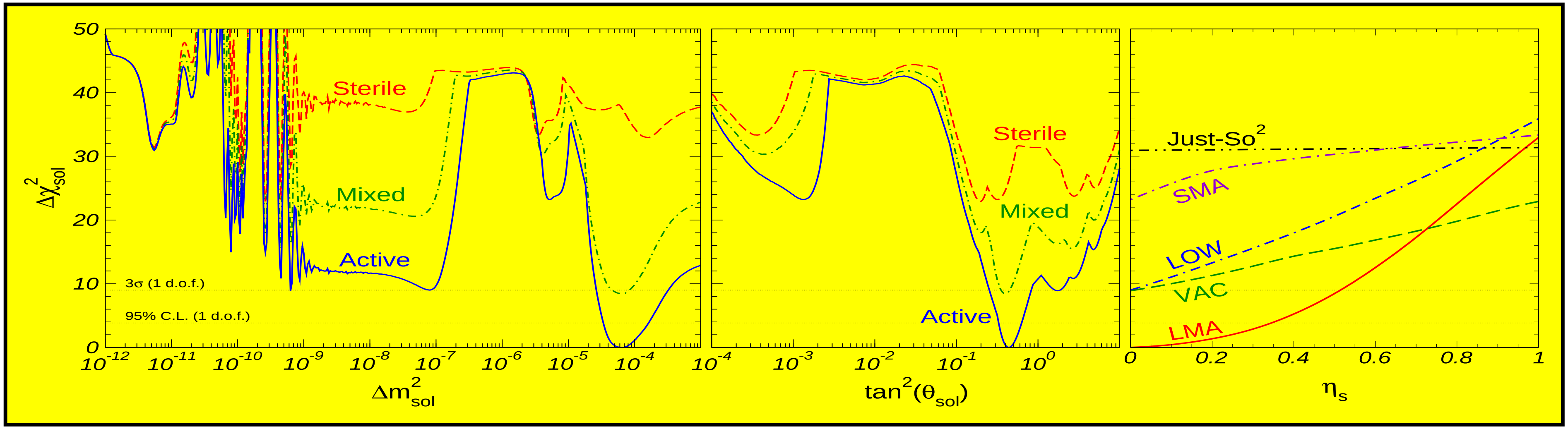




solar-only oscillation regions

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



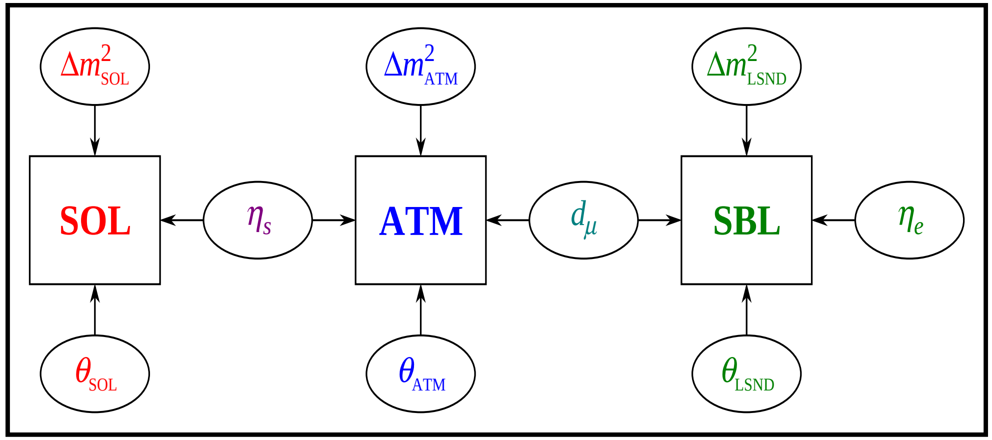


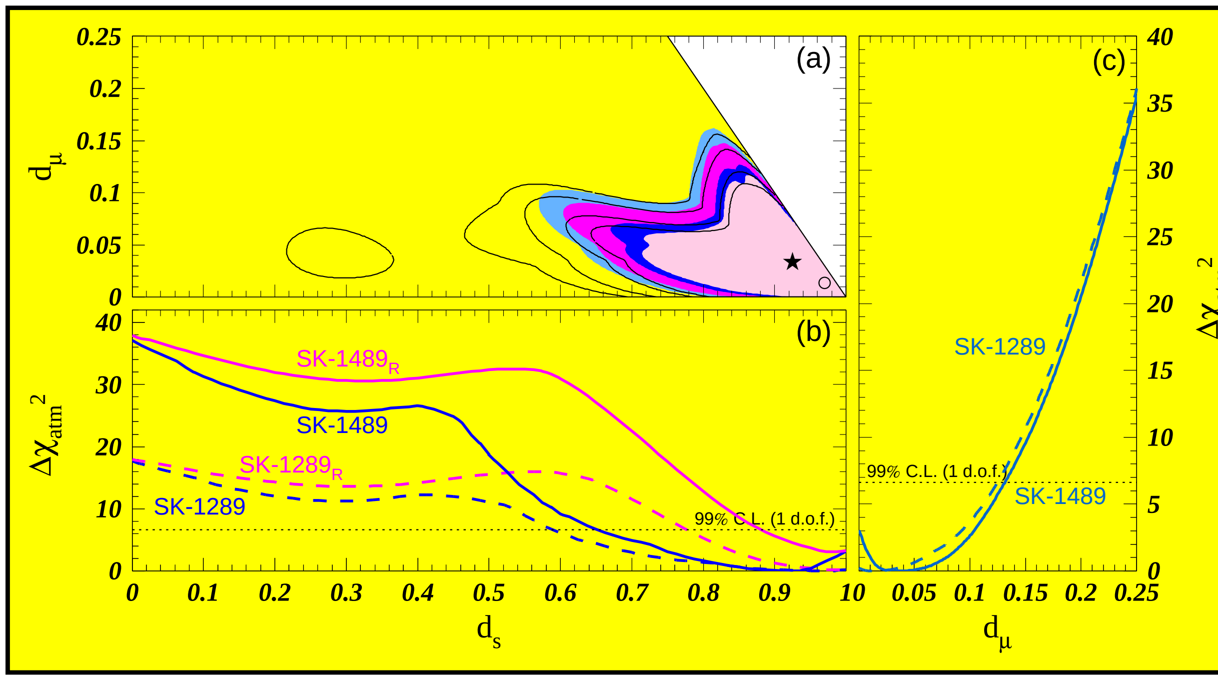
new parameters in atmospheric analysis

sterile as 4th, not 2nd

neglecting CP phases there are 6 angles in lepton mixing matrix
Schechter, JV PRD22 (1980) 2227

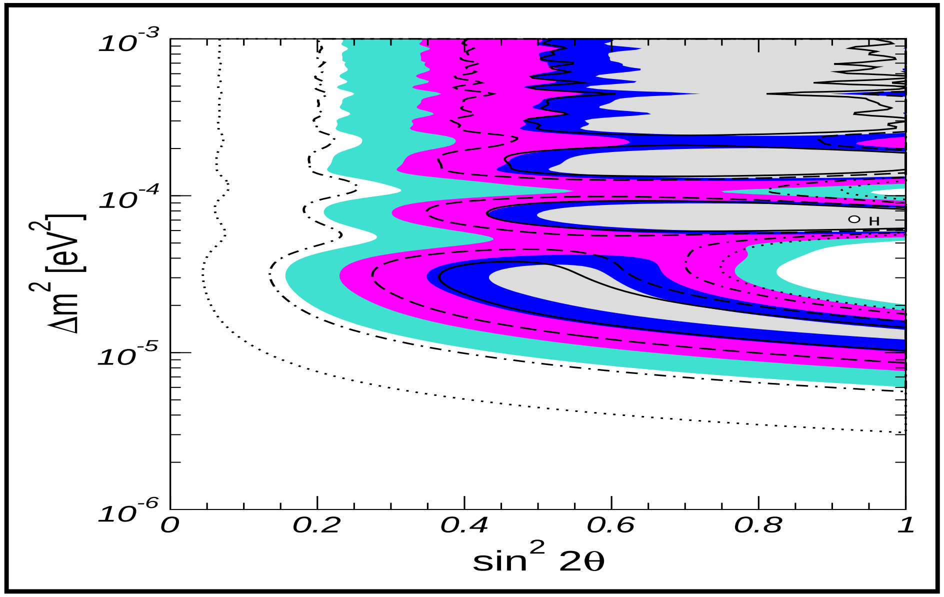
Maltoni et al PRD65 (2002) 093004





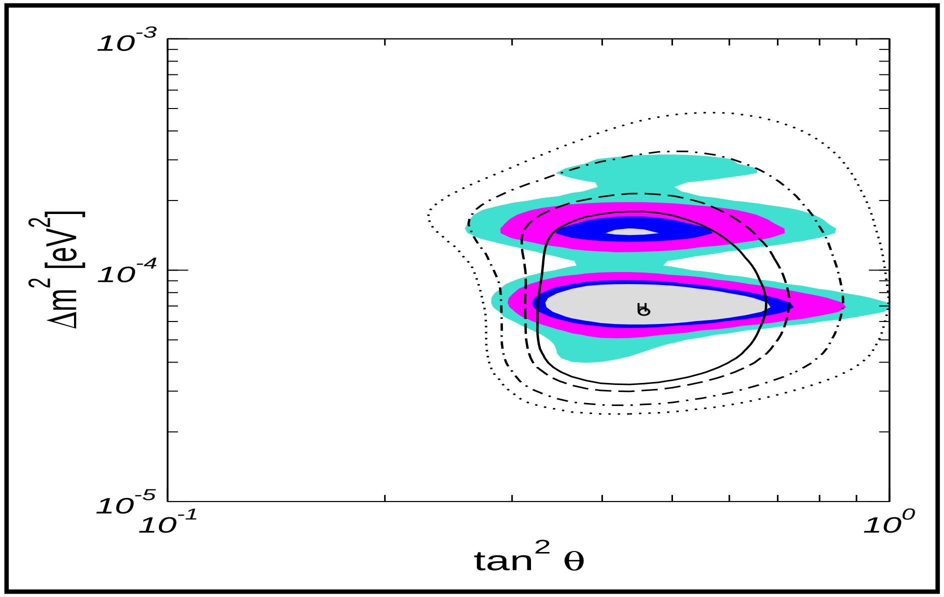
sterility rejection sensitive to new parameters

Implications of first KamLAND reactor results



Maltoni, Schwetz & JV, hep-ph/0212129

first 145-days data support oscillation hypothesis



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

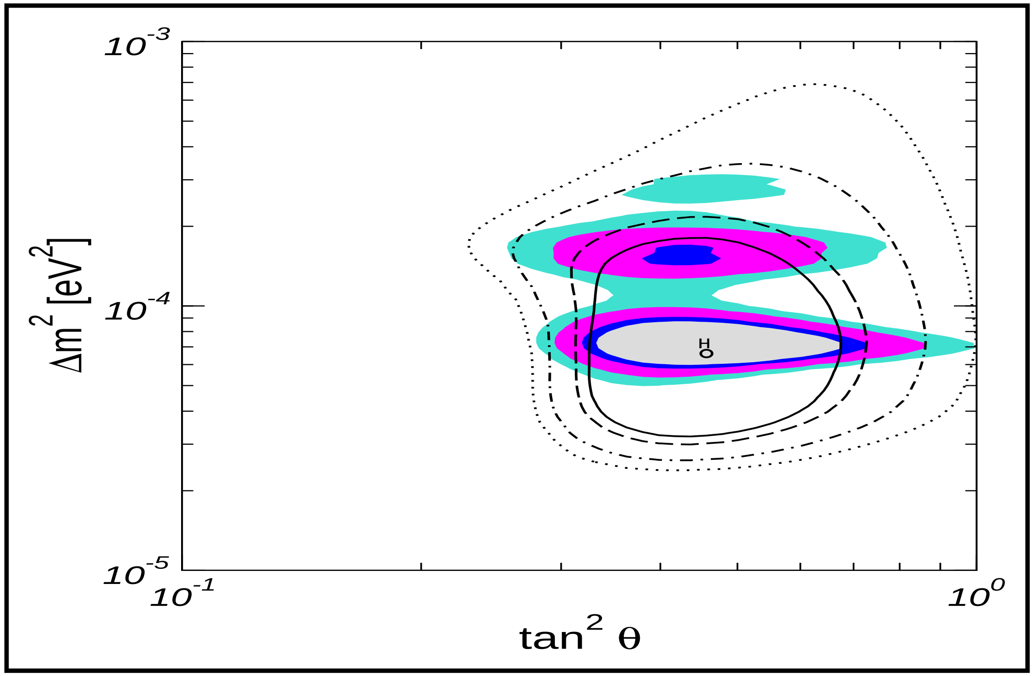
$\Rightarrow$ **oscilllations happen inside the sun!**

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

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

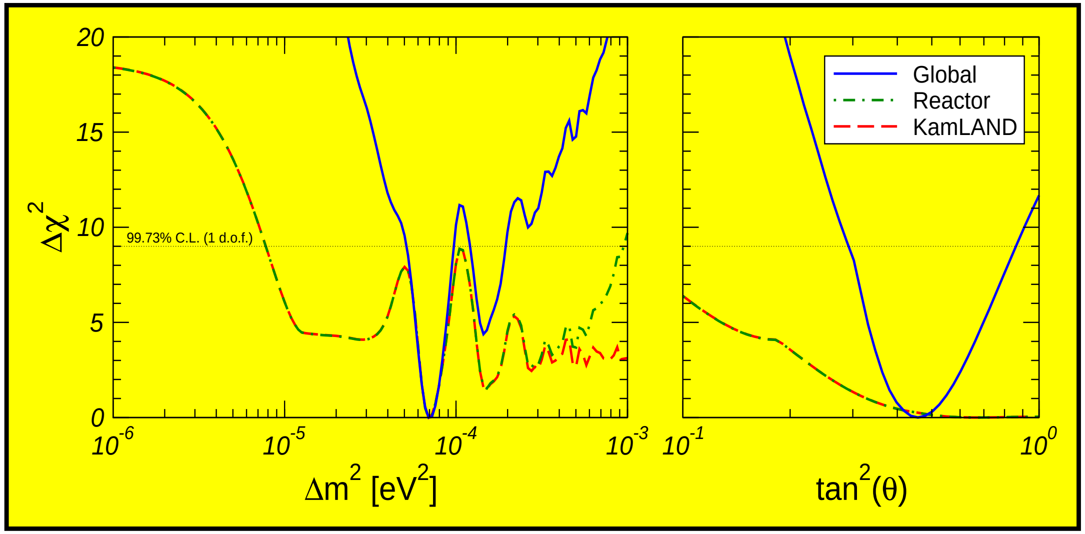
$$1.2 \times 10^{-4}\ \mathrm{eV}^2 \leq \Delta m^2_{\mathrm{SOL}} \leq 1.9 \times 10^{-4}\ \mathrm{eV}^2.$$

Implications of first KamLAND results-2



Maltoni, Schwetz & JV, hep-ph/0212129

consistency with Poisson method



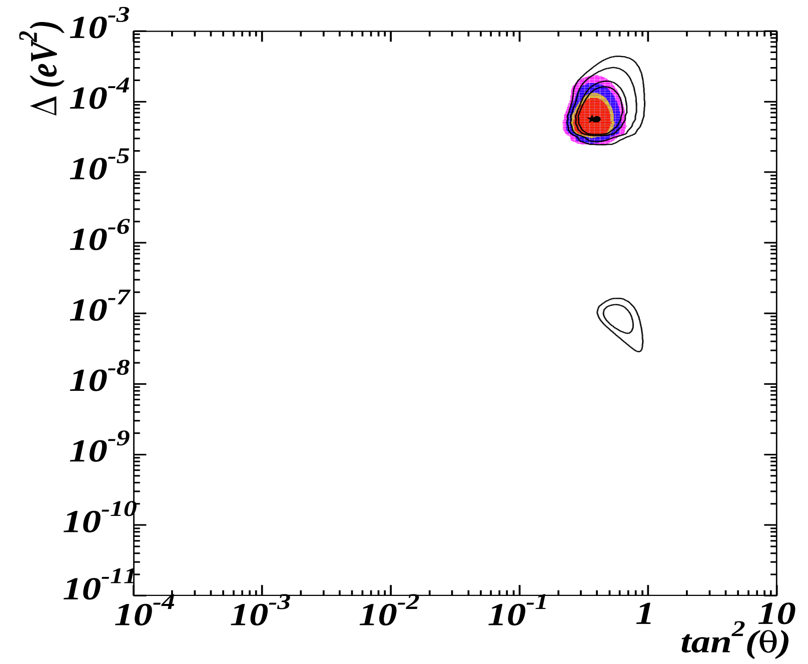
in contrast to atmospheric, solar mixing remains significantly non-maximal

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 MeV,
  $\mathrm{E_{bind}} = 3 \times 10^3$ erg
  $\tau \equiv T_{\nu_h}/T_{\bar{\nu}_e}$=1.4
- pre-KamLAND

  solar+SN1987A analysis

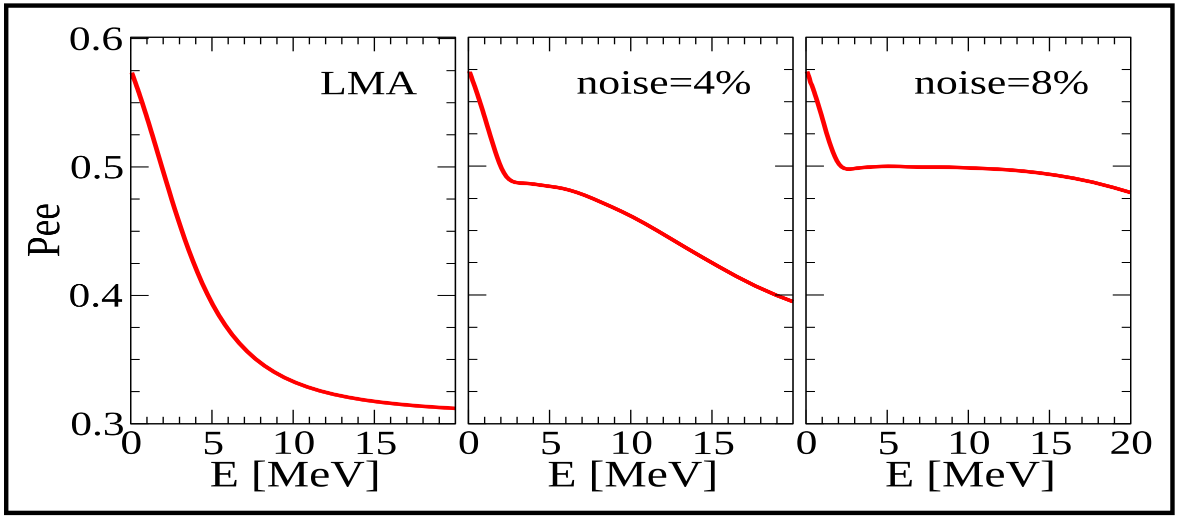


Kachelriess et al PRD65 (2002) 073016

LMA-MSW may remain best

Robustness of MSW plot

Burgess et al, ApJLett, hep-ph/0209094

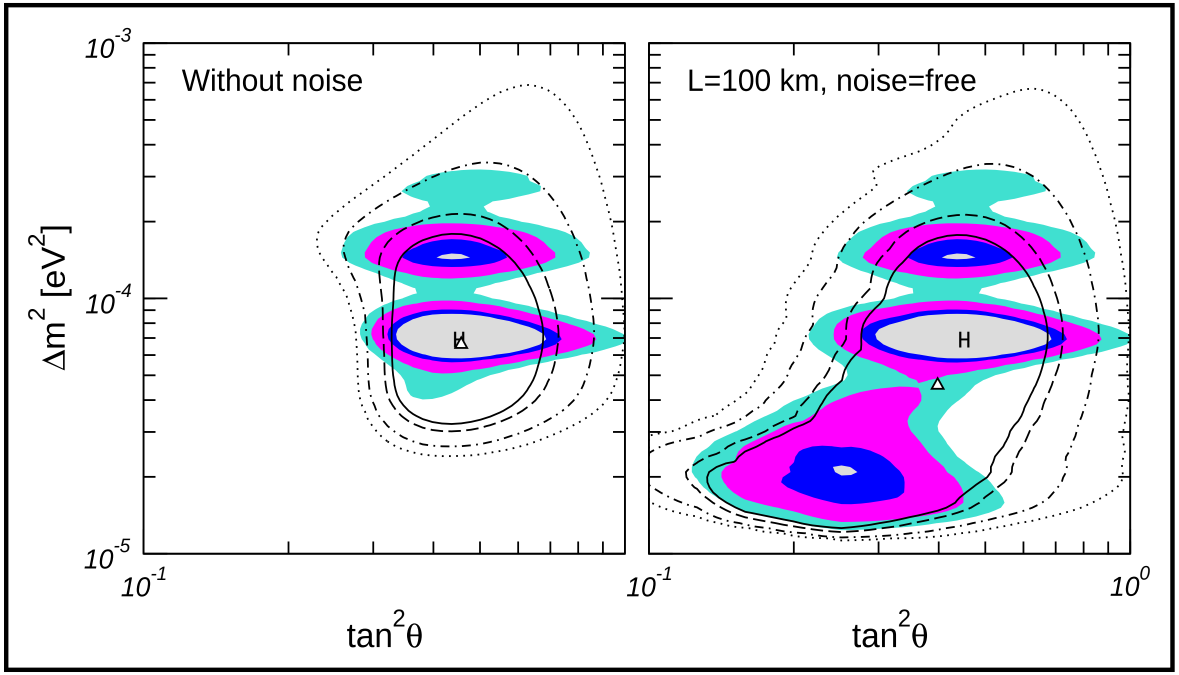


neutrino propagation strongly affected by density noise

Balantekin et al 95

Nunokawa et al NPB472 (1996) 495

Burgess et al 97

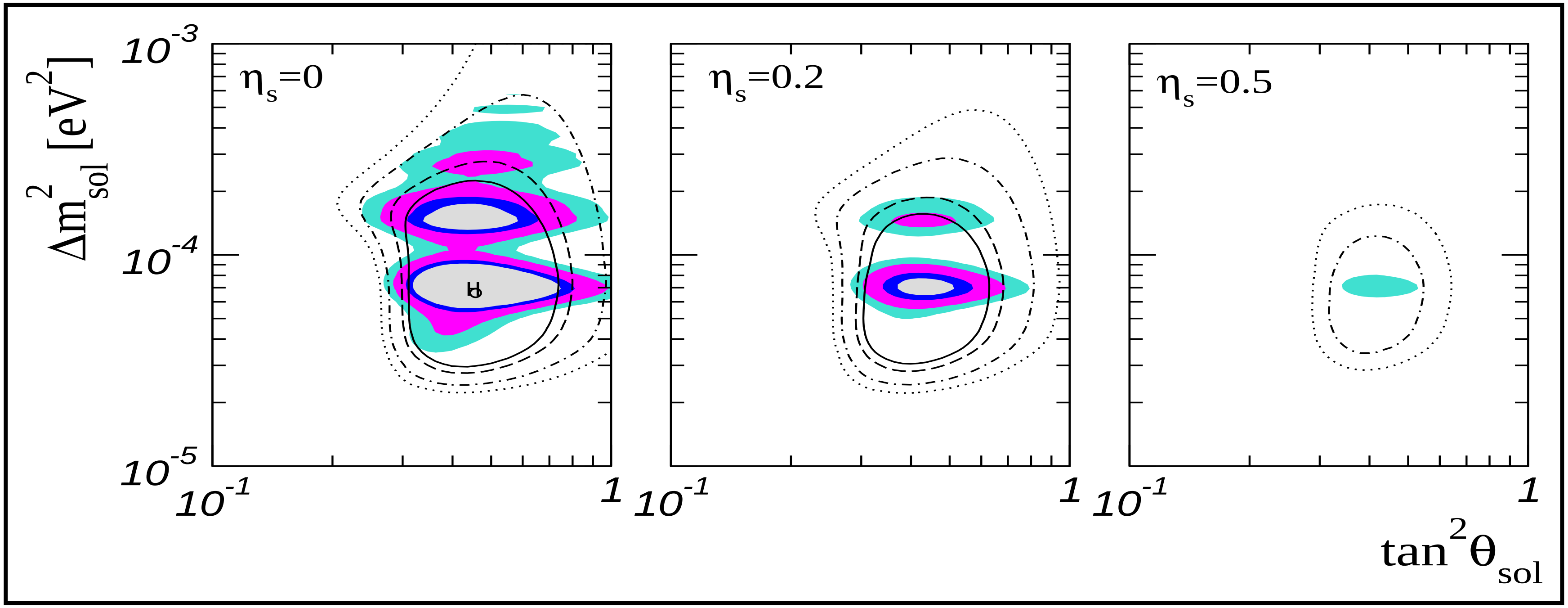


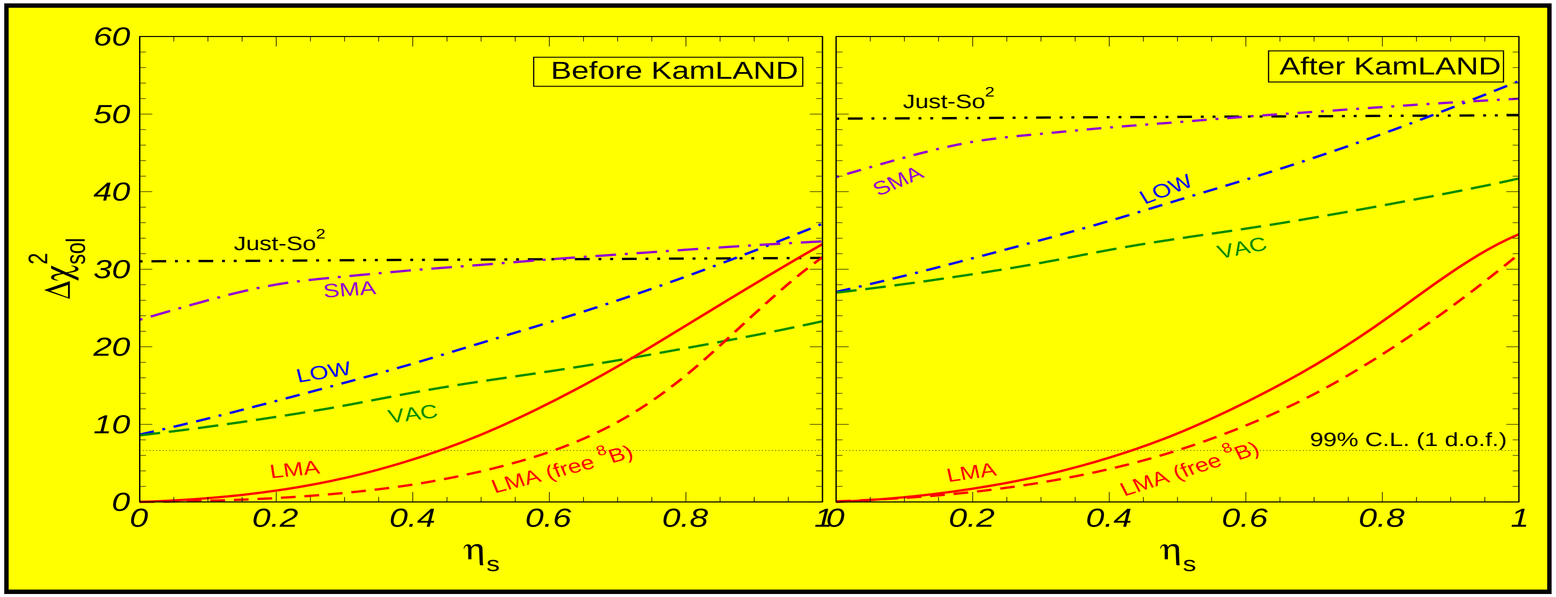
substantial distortion

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

solar+KamLAND: sterility rejection

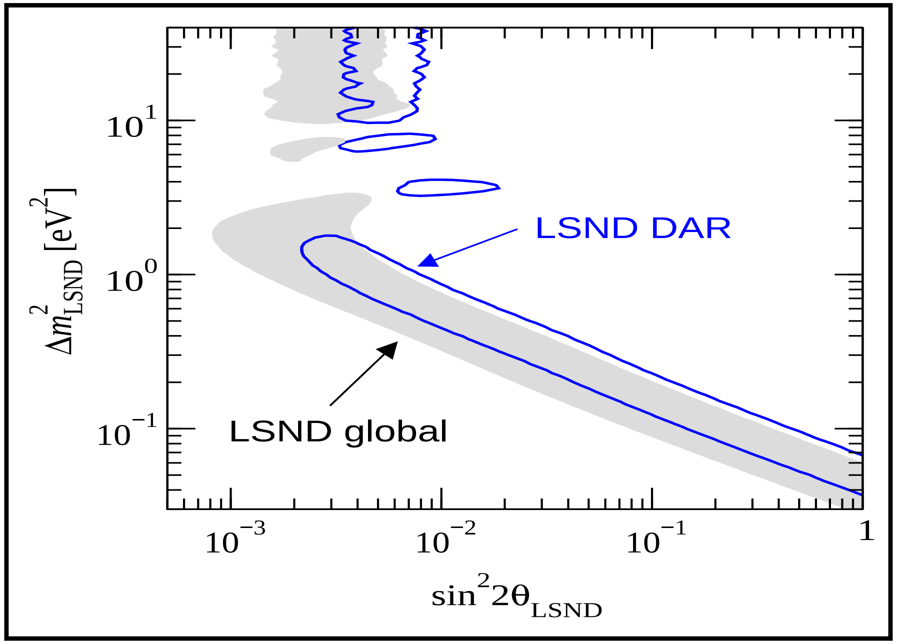
Maltoni et al PRD **67** (2003) 013011





LSND

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



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

ATM

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

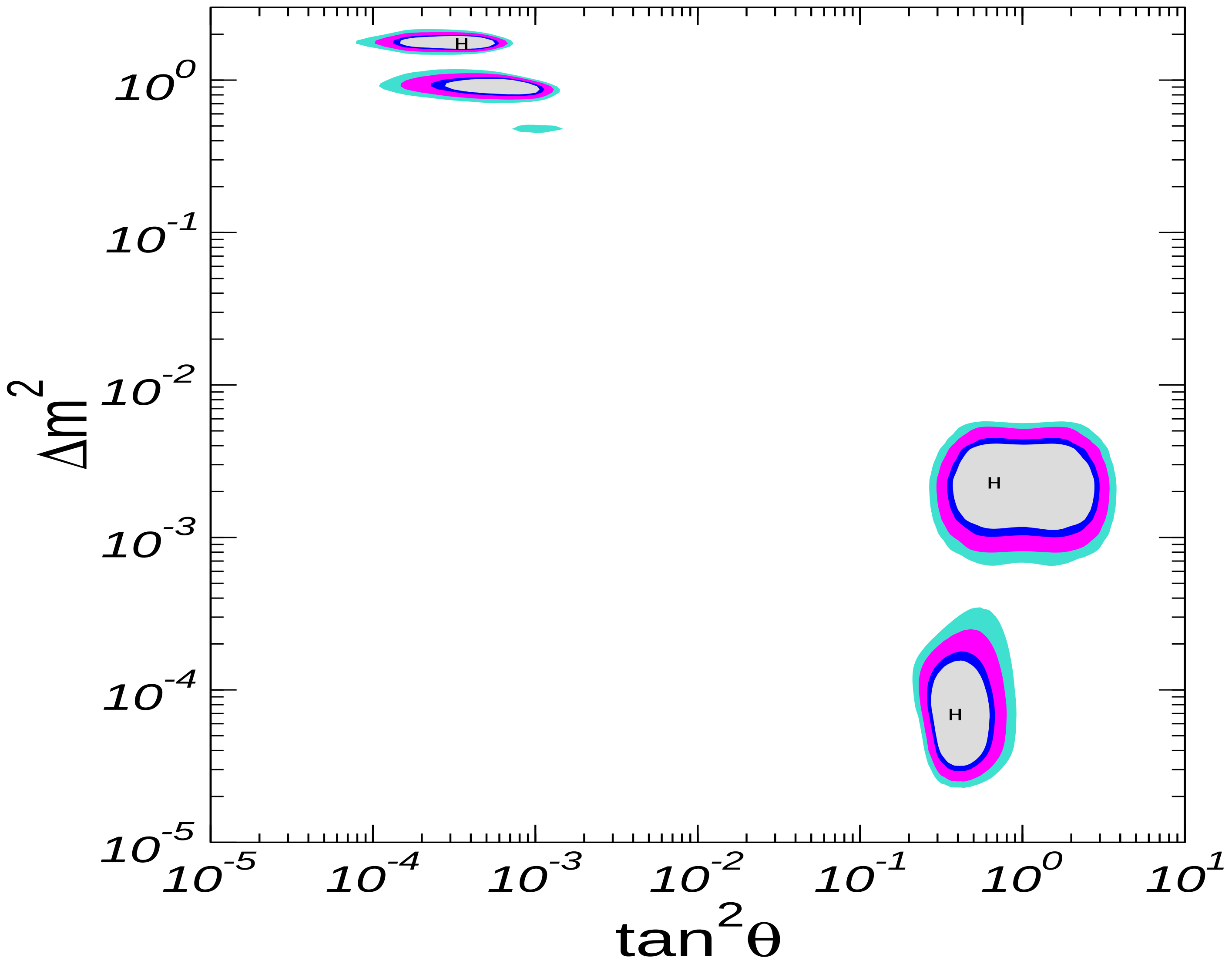
Peltoniemi, Tommasini and JV, PLB **298** (1993) 383

Caldwell-Mohapatra PRD48 (1993) 325

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

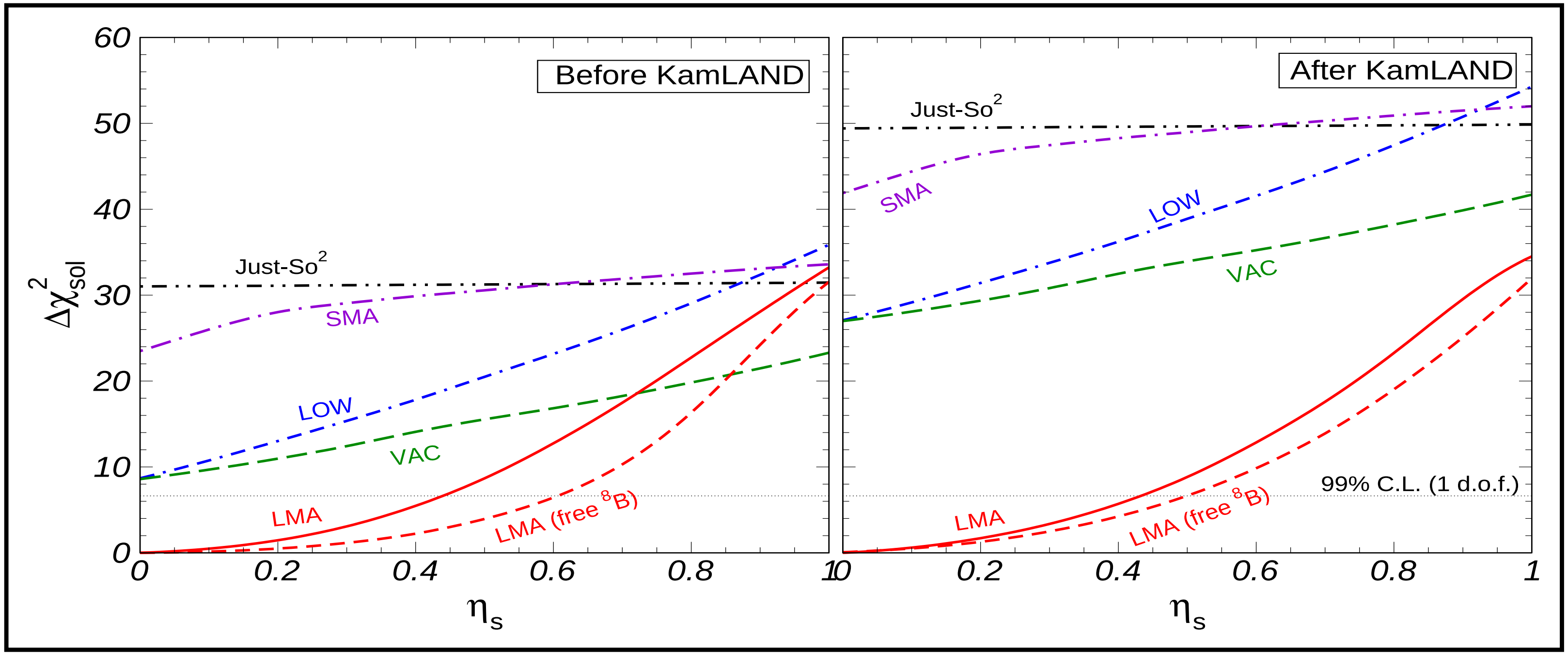
SOL

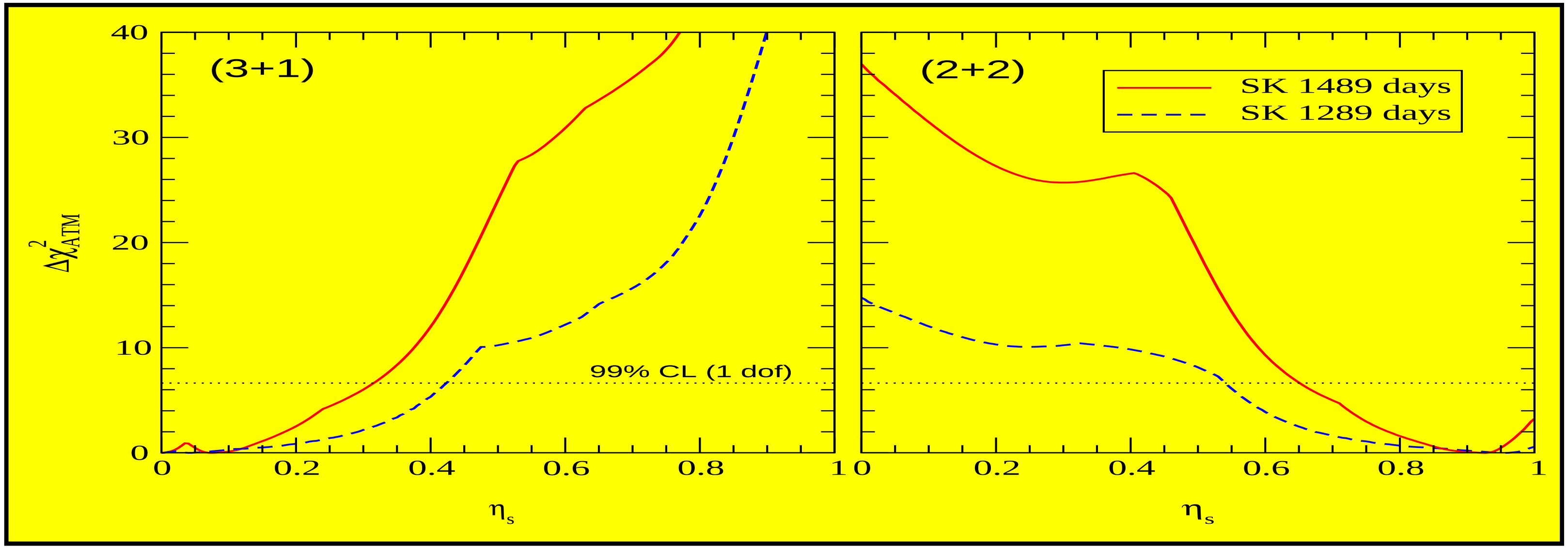
can one fit all current nu-data with oscillations ?



stronger sterility rejection by solar & atm data

from SK-1496d-sol + SNO-NC: Maltoni et al PRD **67** (2003) 013011

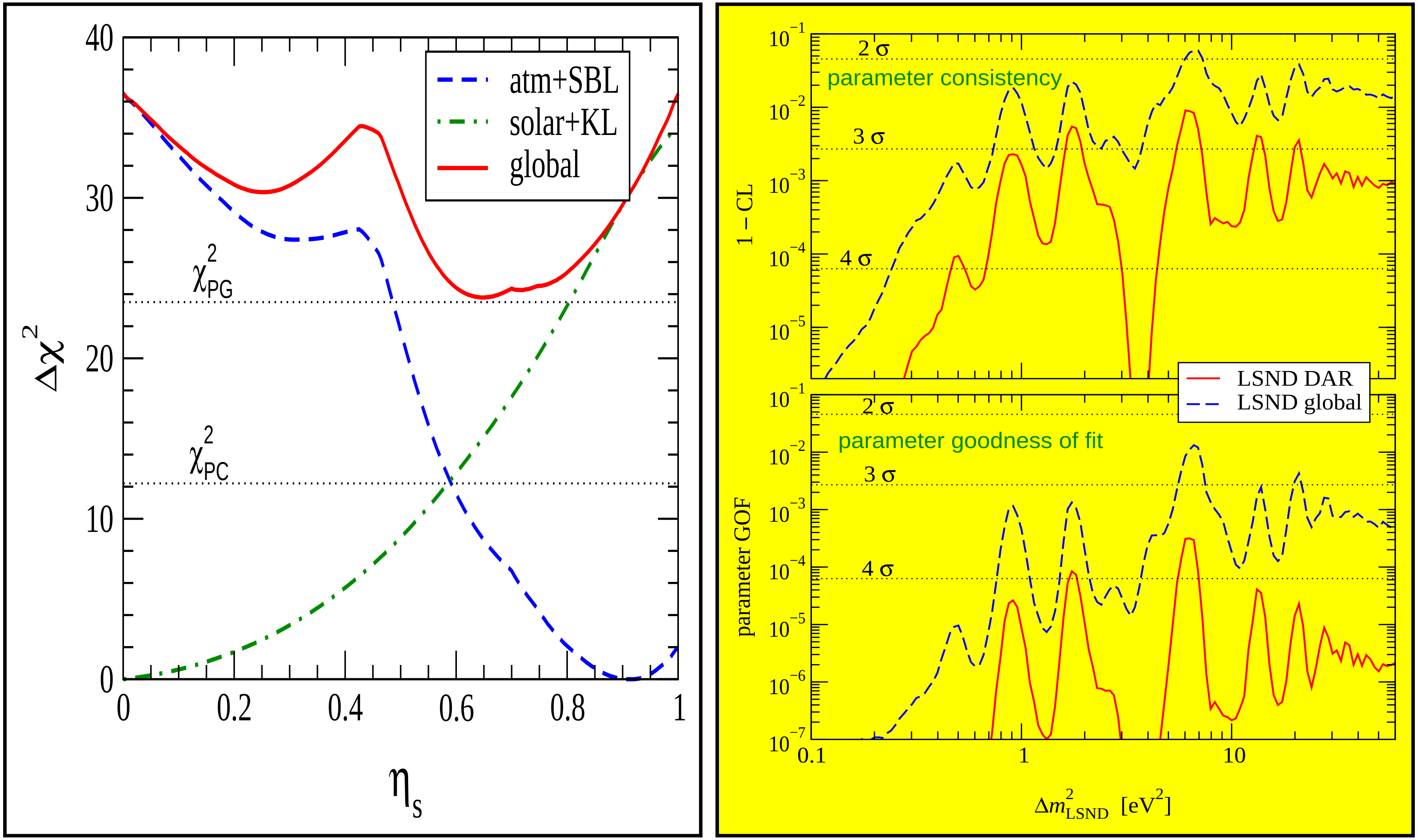




4-nus do not fit LSND with sol+atm

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

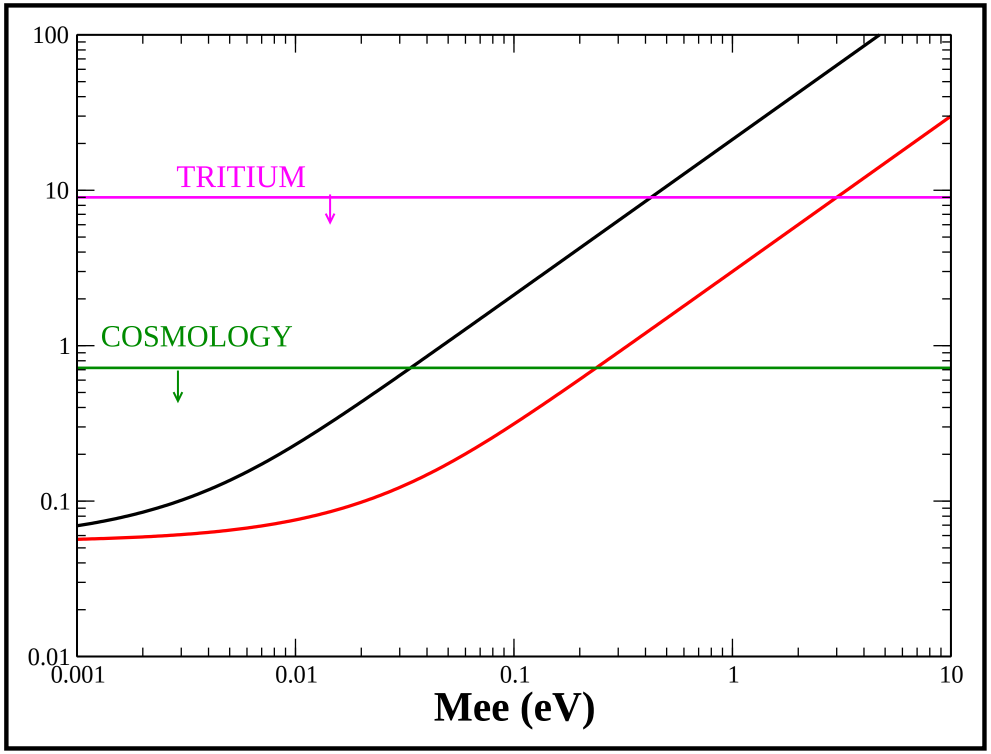
in contrast to oscillations

cosmology can probe absolute m-nu scale

tritium beta decay experiments

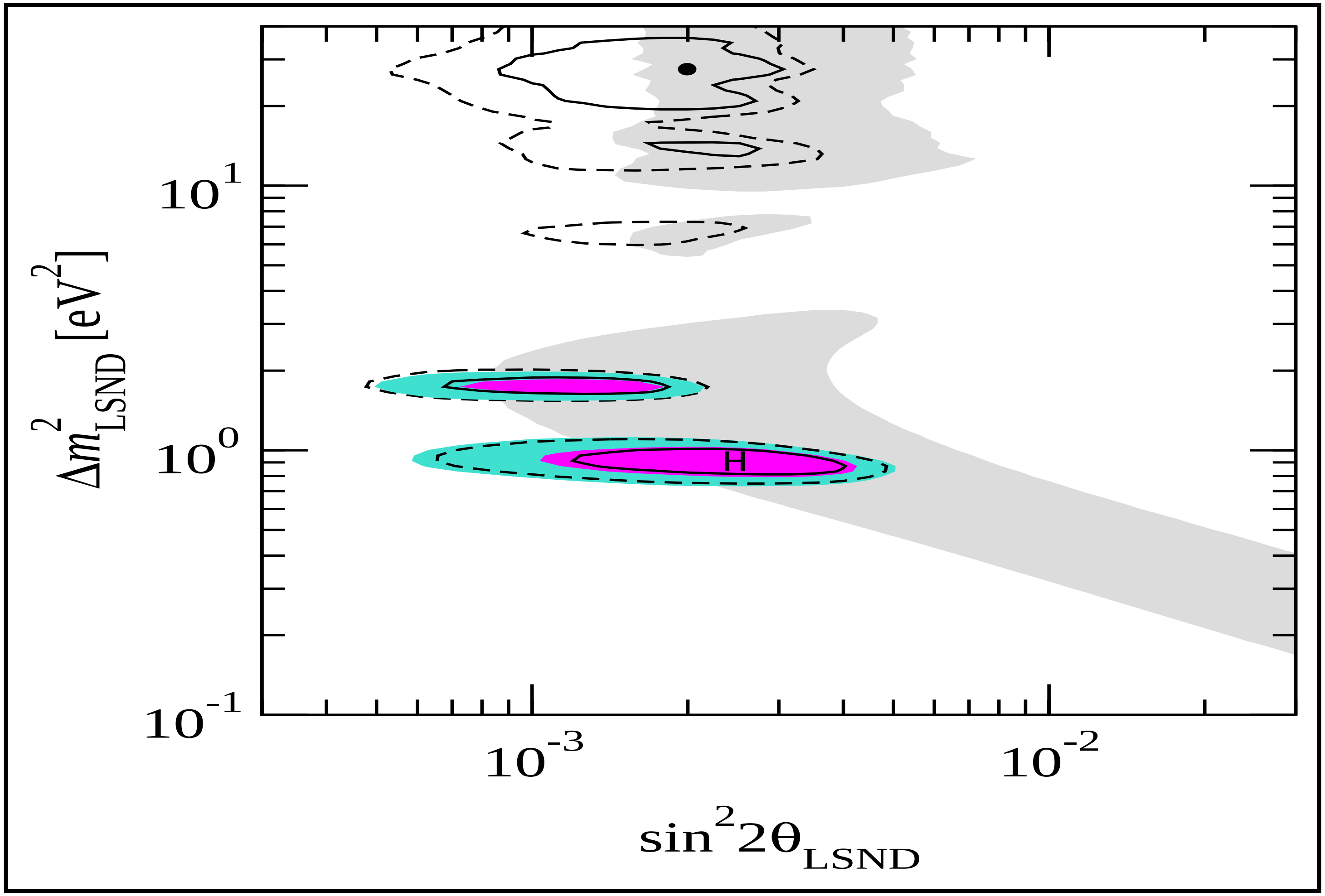
CMB bound on hot dark matter component (2DF, WMAP, ...)

neutrinoless double beta decay



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

Cosmology closes in on LSND



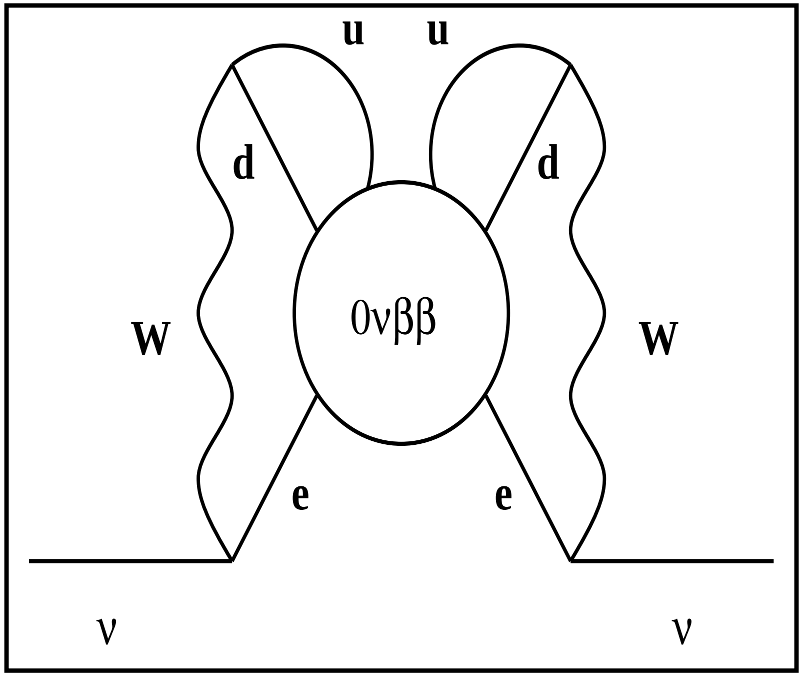
Preliminary, Maltoni et al

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

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

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

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



no such theorem for flavor violation!

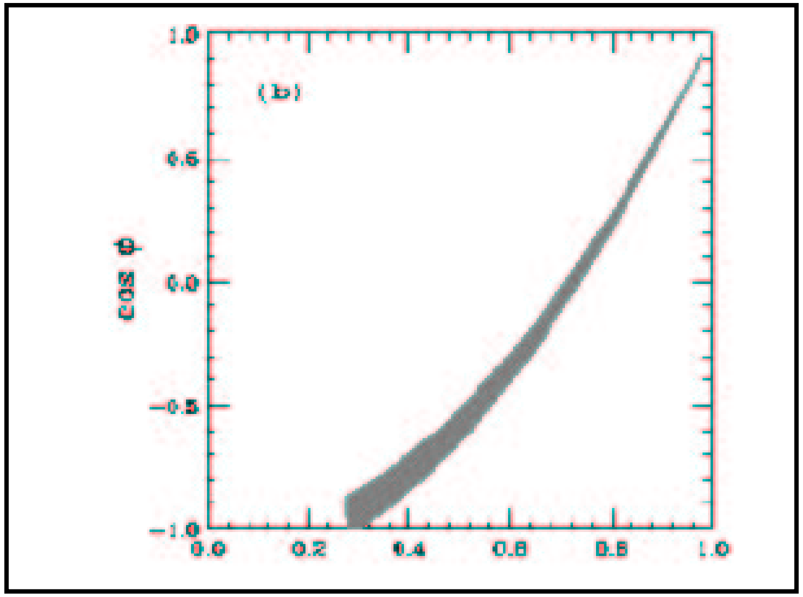
like other L violating processes
$\beta\beta_{0\nu}$ is sensitive to Majorana phases

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

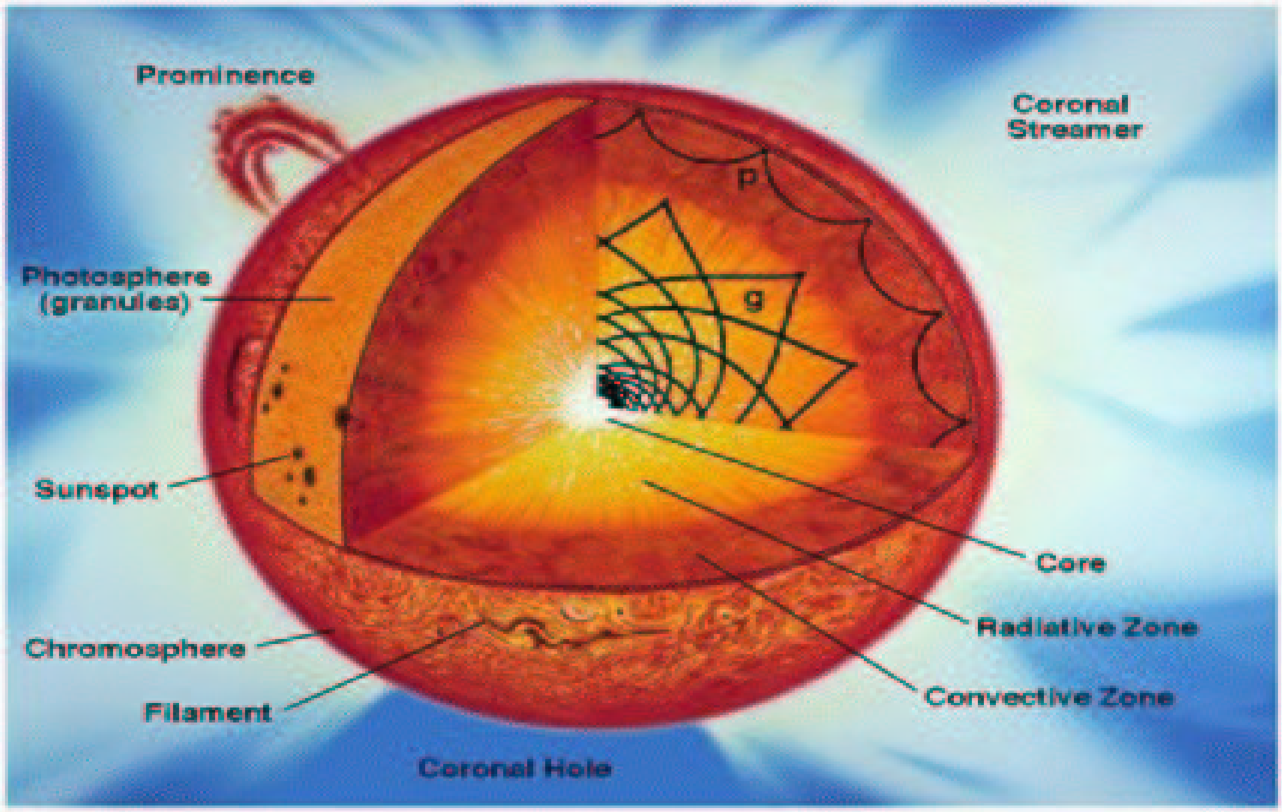
Wolfenstein PLB107 (1981) 77; Doi et al

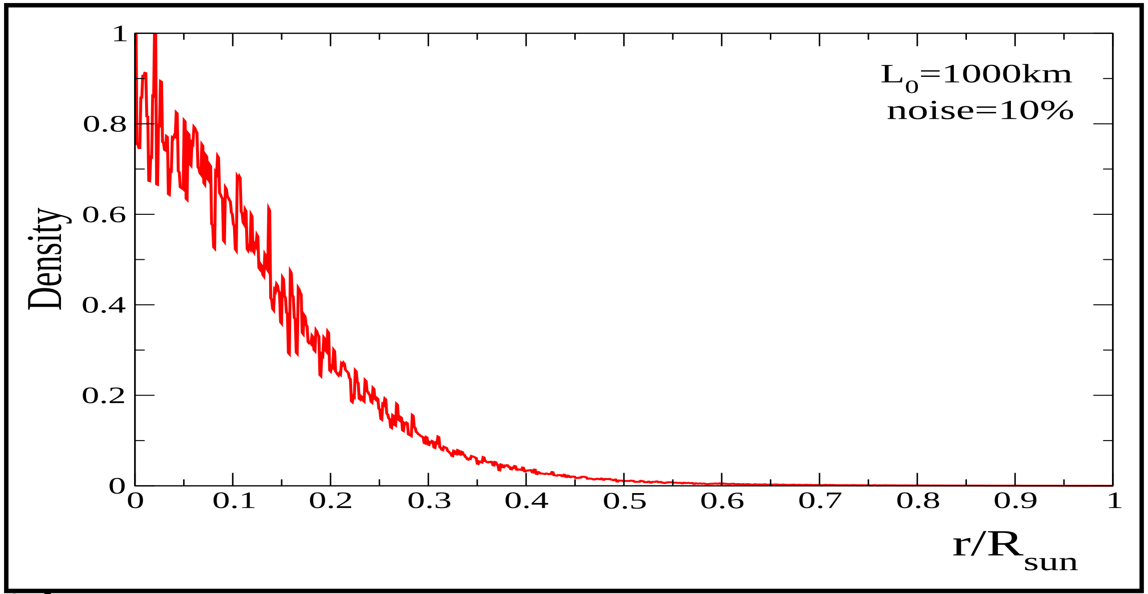
can not reconstruct majorana phases

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



Neutrinos as astro probe

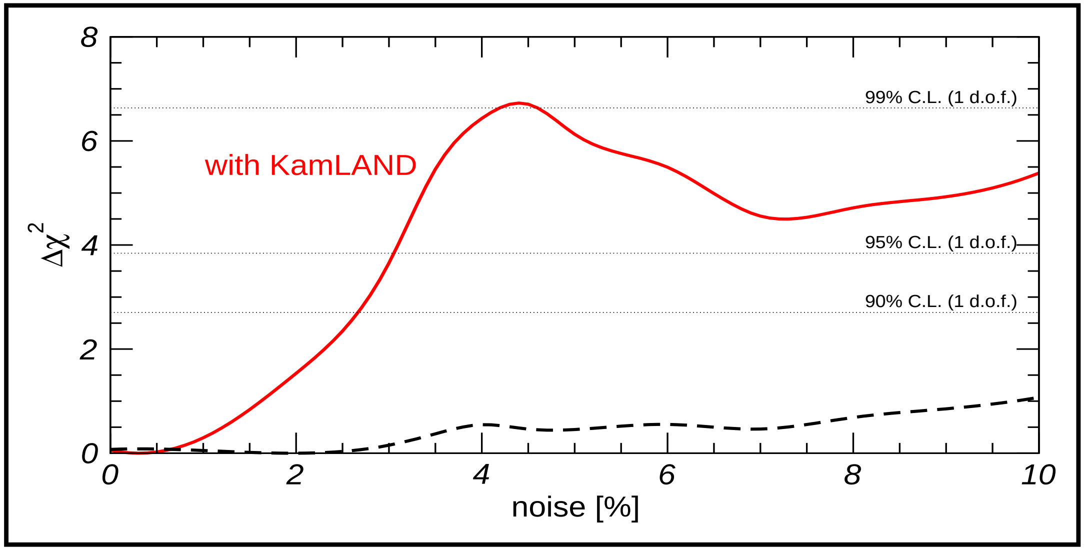

Prominence
Coronal Streamer
p
g
Photosphere (granules)
Sunspot
Core
Radiative Zone
Chromosphere
Convective Zone
Filament
Coronal Hole


L_0=1000km
noise=10%
Density
r/R_{sun}
0
0.2
0.4
0.6
0.8
1
0.1
0.3
0.5
0.7
0.9

neutrinos as deep solar probe

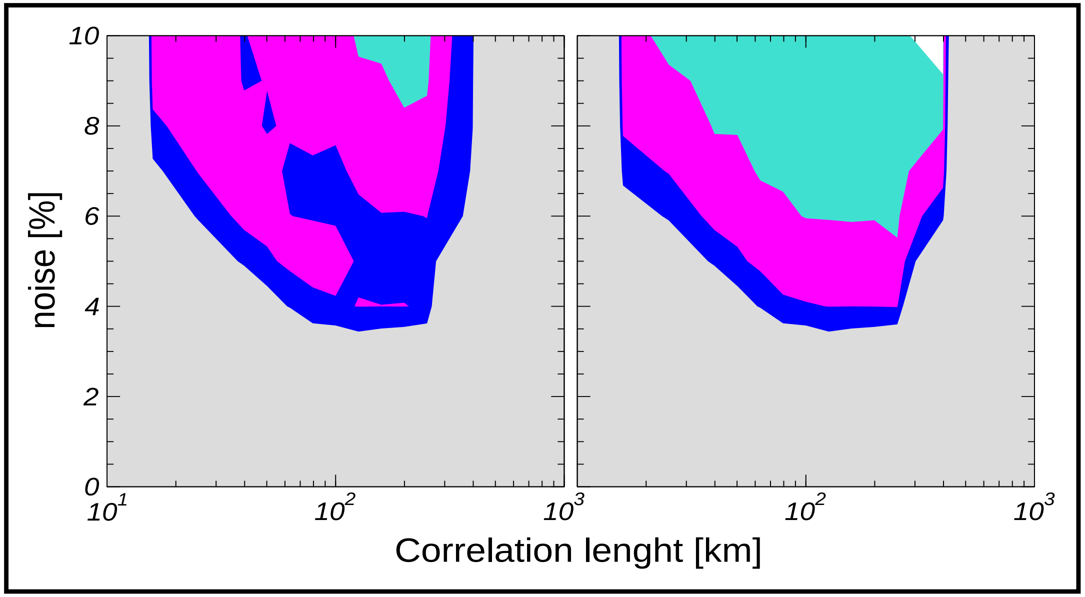
Burgess et al, Astrophys.J.588:L65,2003 [hep-ph/0209094] & astro-ph/0304462

$L_0 = 100\text{Km}$



KamLAND as solar probe

beyond helioseismology



free vs BFP

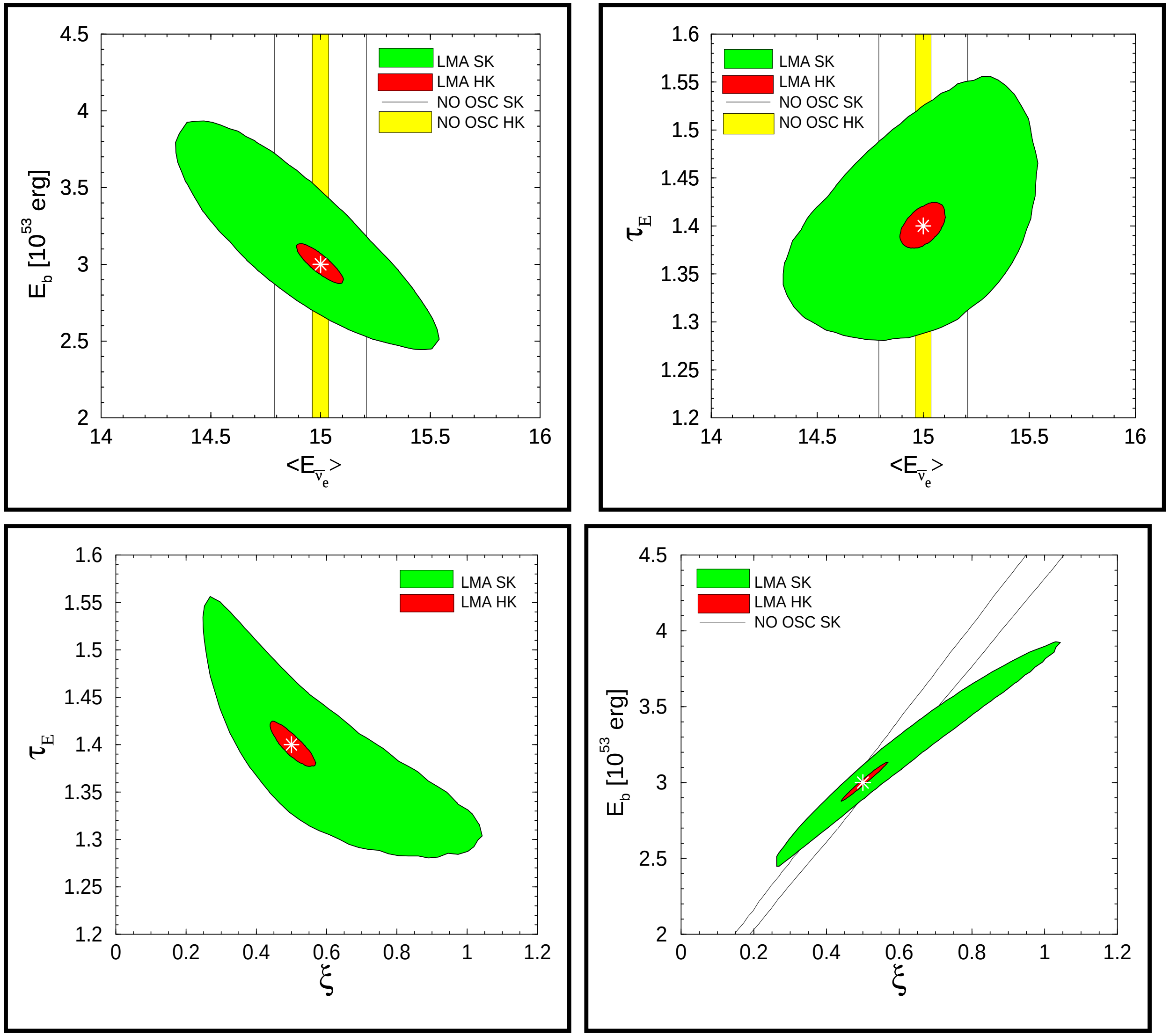
neutrinos as future Supernova probe

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



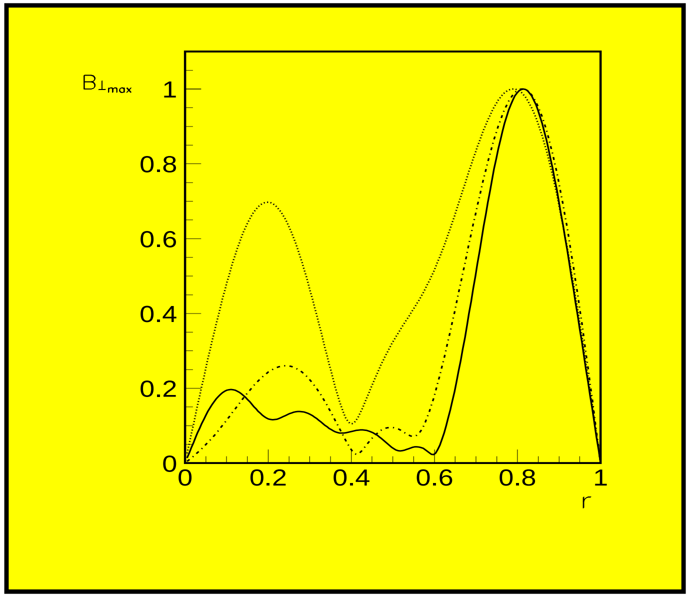
improved supernova parameter determination

alternatives to oscillations?

Oscillation vs Spin Flavor Precession

Spin Flavor Precession

Schechter, JV PRD24 (1981) 1883 & D25, 283
Akhmedov PLB213 (1988) 64
Lim-Marciano PRD37 (1988) 1368



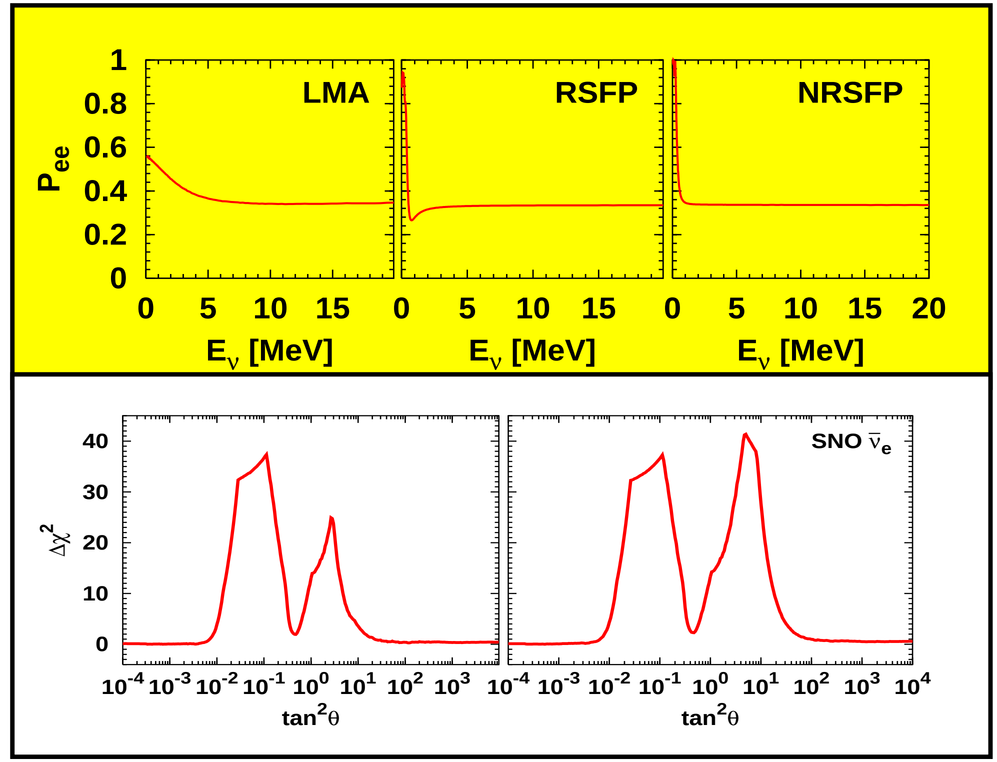
MHD fixes B-profile

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 ν_e -conversion probability

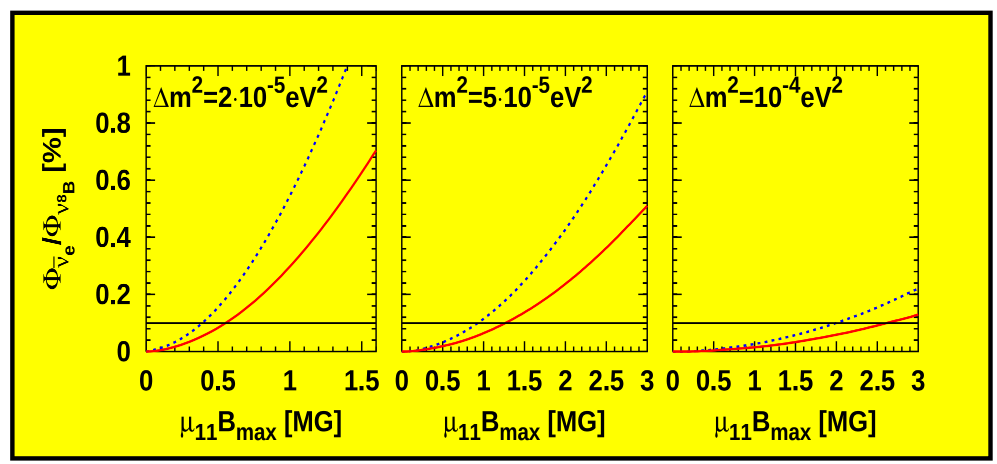


LMA-MSW, RSFP, NRSFP equivalent

KamLAND lifts degeneracy

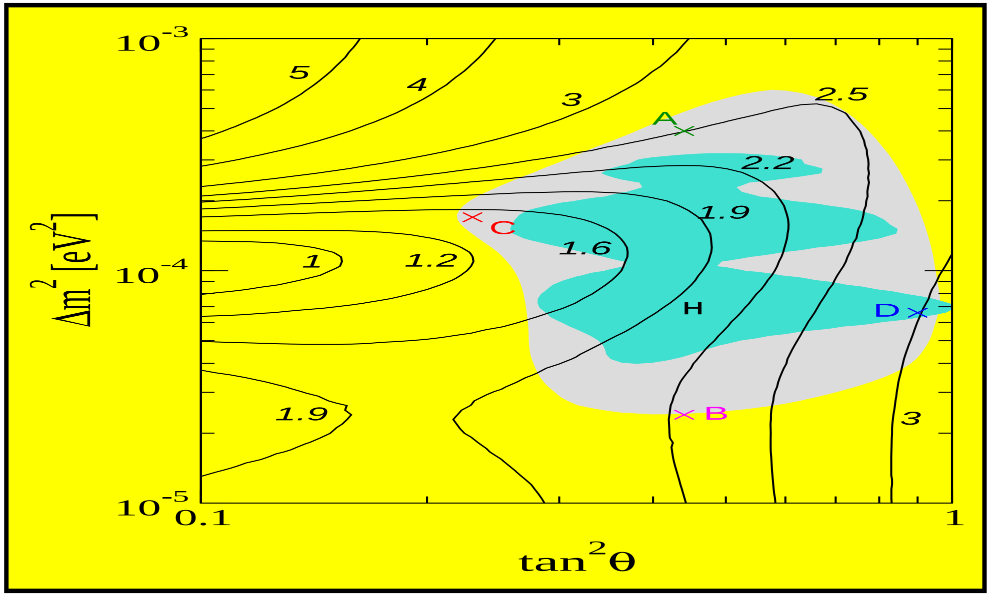
ruling out SFP as main solution

testing SFP as sub-leading



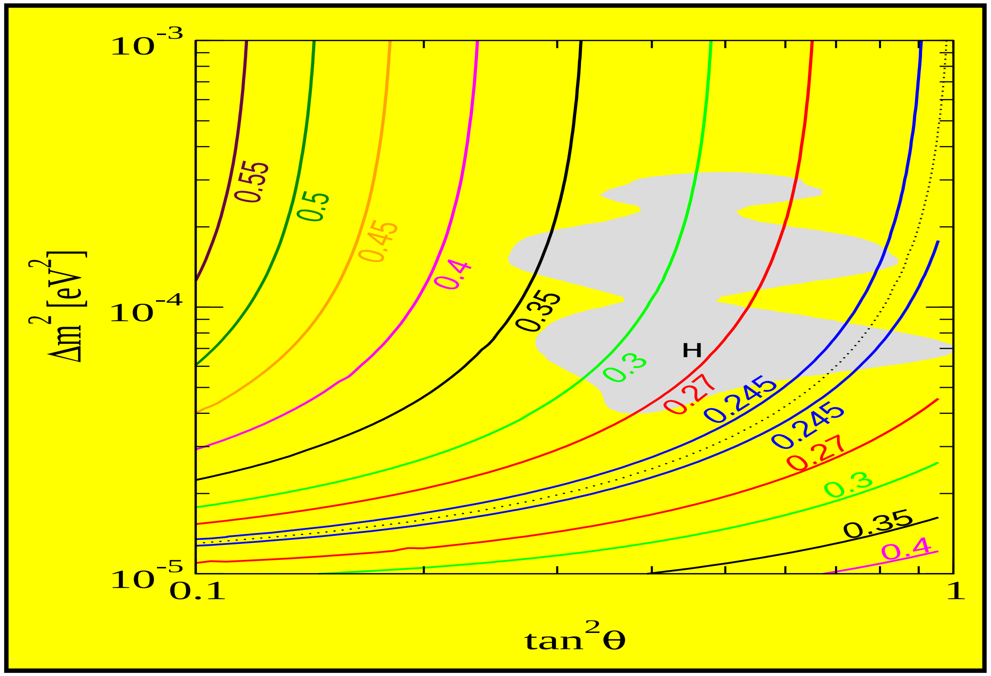
probing neutrino magnetic moments at LMA-MSW

present sensitivity



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

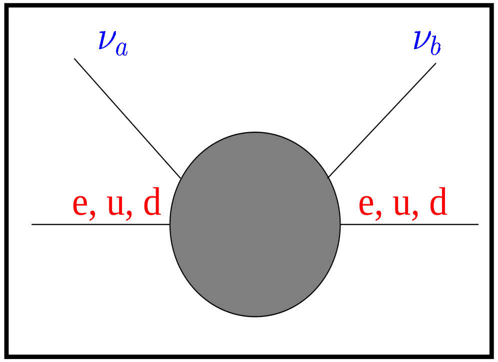
expected Borexino sensitivity



Oscillation vs NSI

Non-standard interactions

FC or NU sub-weak strength dim-6 terms εG_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

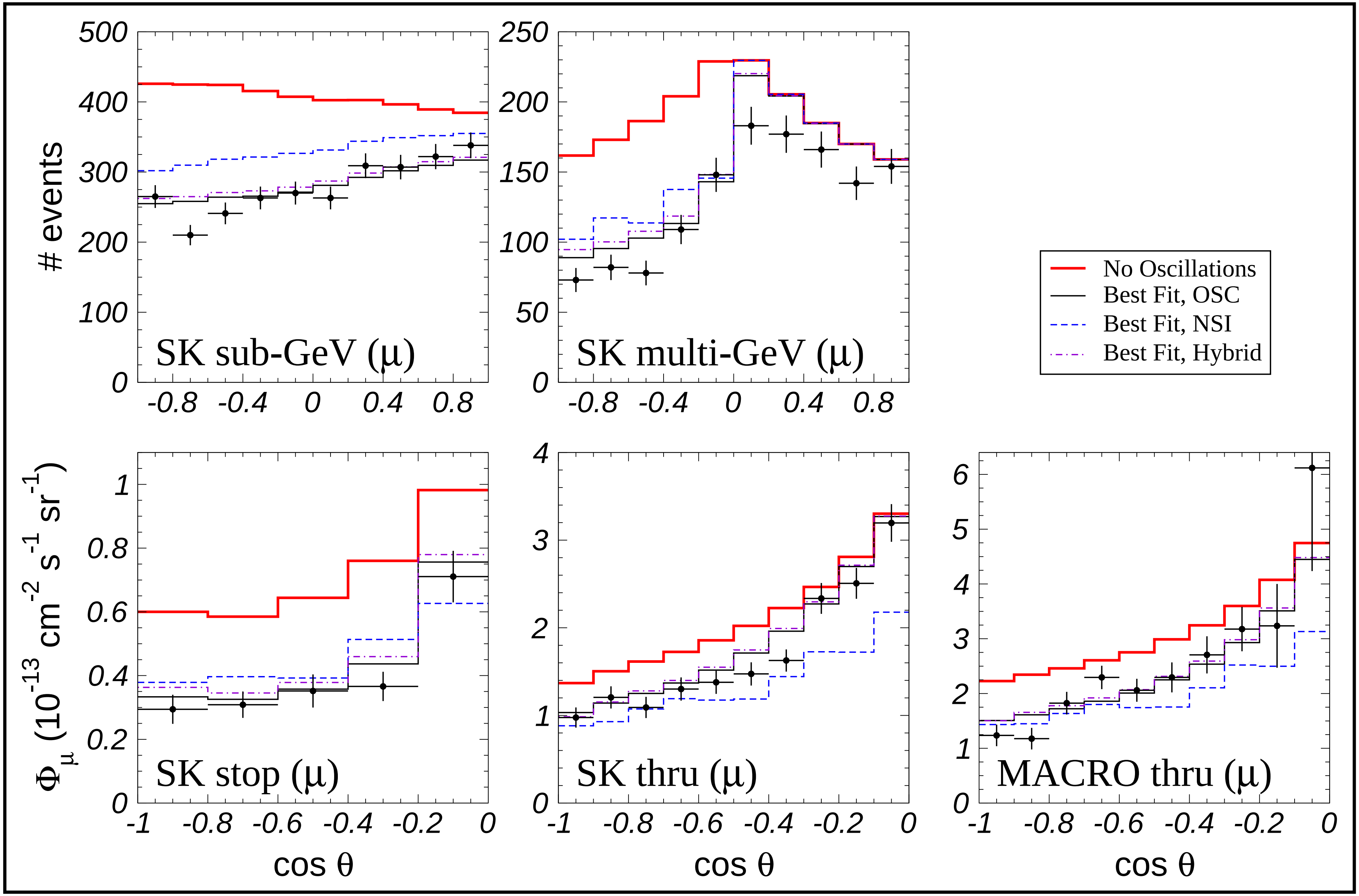
excellent description of solar data

Guzzo et al NPB629 (2002) 479

KamLAND implies not the leading mechanism

How robust are atmospheric oscillations?

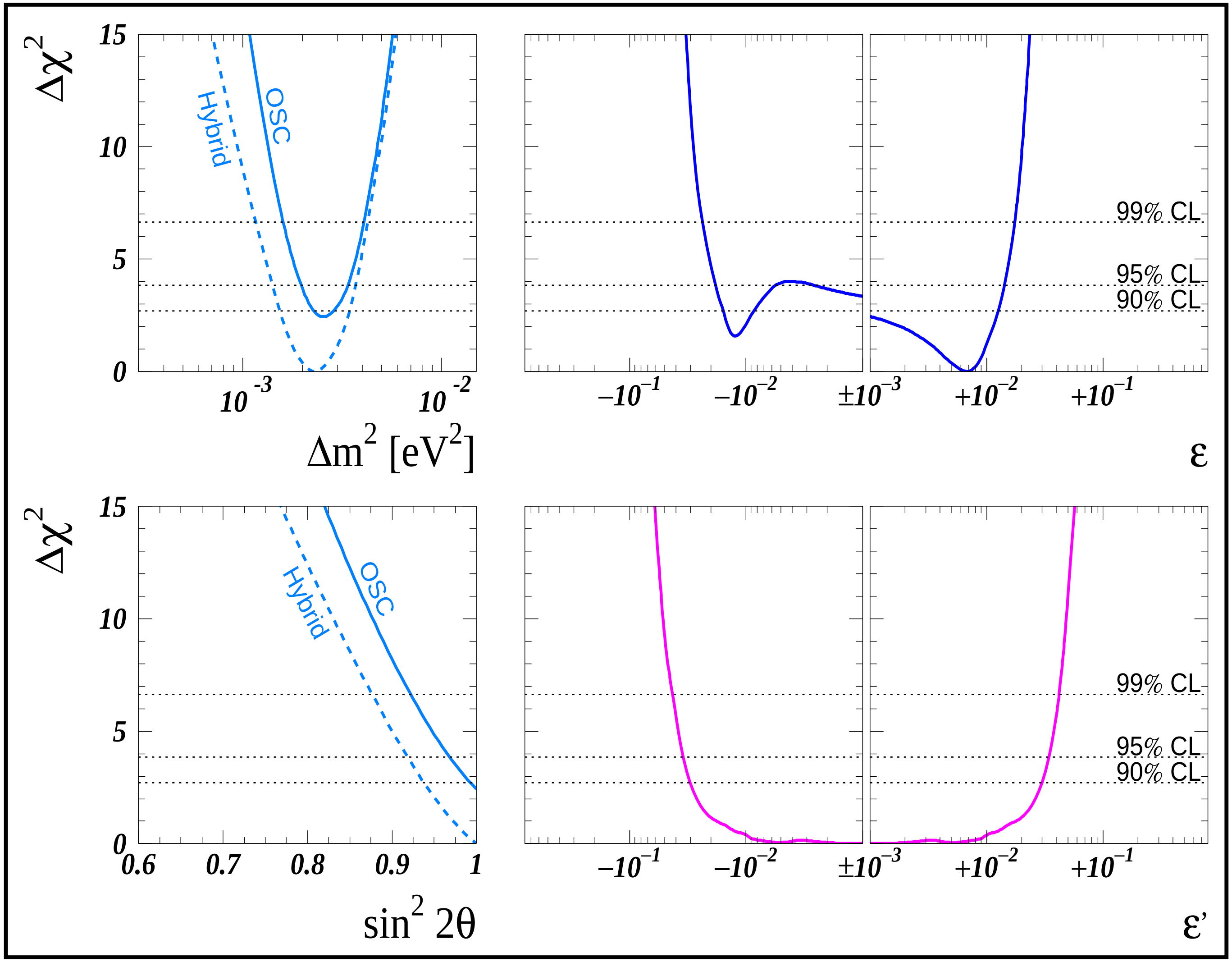
very good contained atm-fit, Gonzalez-Garcia et al, PRL **82** (1999) 3202



probing NSI with atmospheric data

Fornengo et al,

PRD **65** (2002) 013010

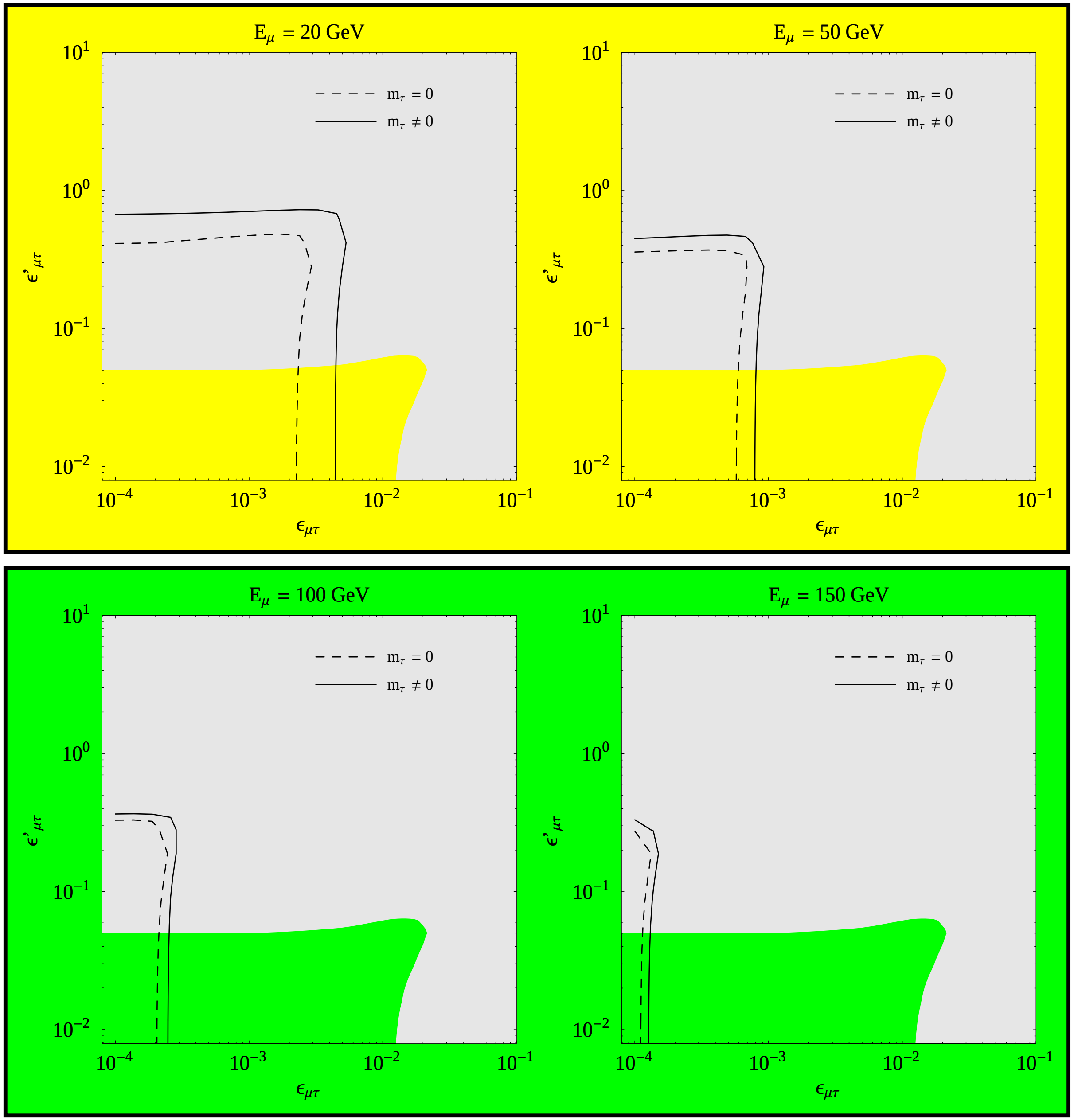


atm bounds on FC and NU nu-interactions

Improved FC-tests at NuFact

Huber & JV PLB **523** (2001) 151

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



θ_{13} and Leptonic CP Violation

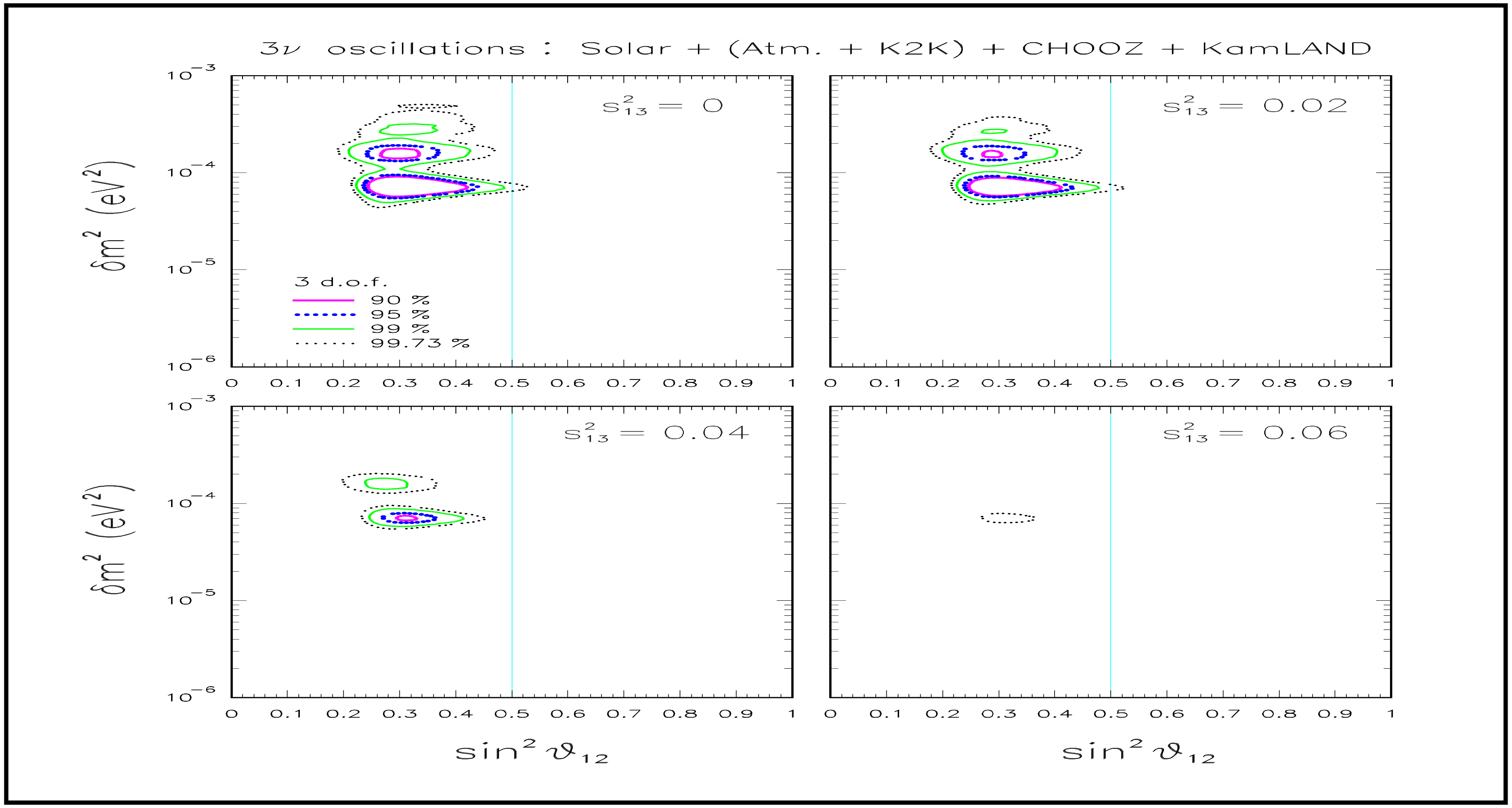
"Dirac" CPV suppressed, since ϕ disappears when any $\Delta_{ij} \to 0$

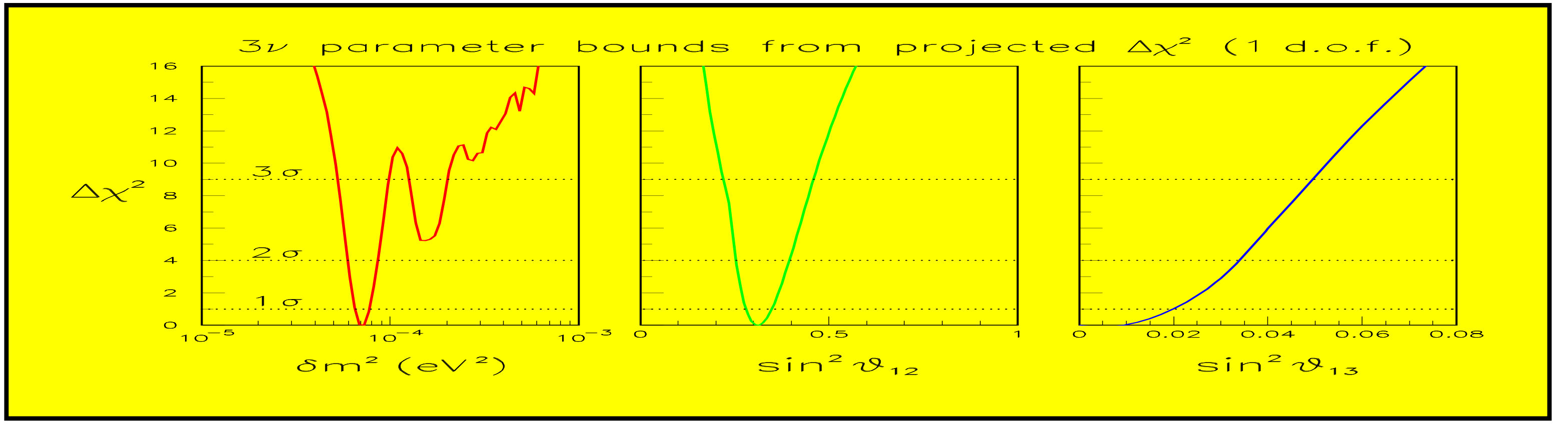
Schechter and J. V., PRD **21** (1980) 309

Constraining θ_{13}

Fogli, Lisi et al, hep-ph/0212127

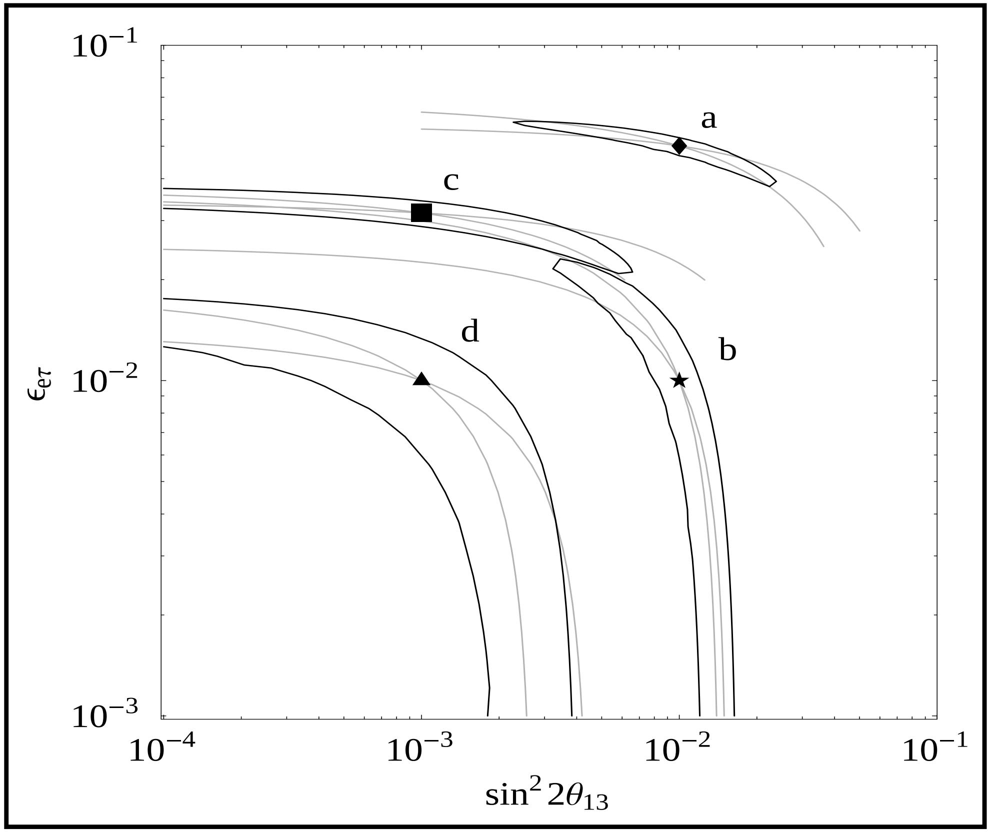
Gonzalez-Garcia et al, PRD63 (2001) 033005





FCI-oscillation confusion theorem

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



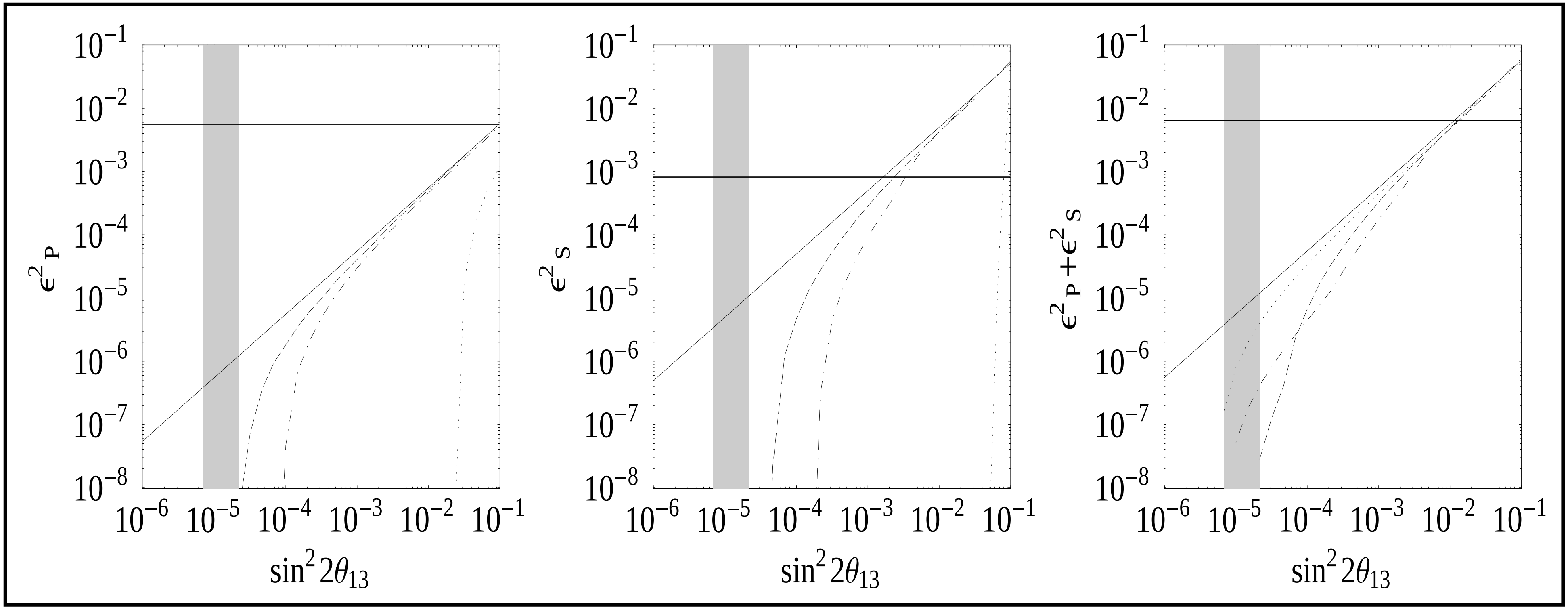
Huber, Schwetz & JV PRL **88** (2002) 101804

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

FCI-oscillation confusion theorem-2

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



2×10^{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 $700\,\text{km}$, dash-dotted for $3\,000\,\text{km}$ and dashed is for $7\,000\,\text{km}$ 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 θ_{ij} | 23=atm   12=sol   13=reac |

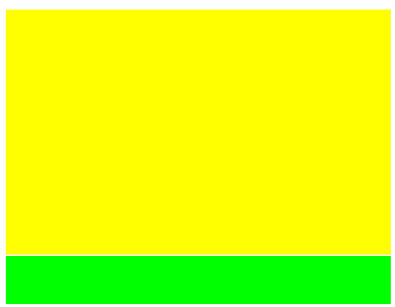
  1 KM-like | ϕ |

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

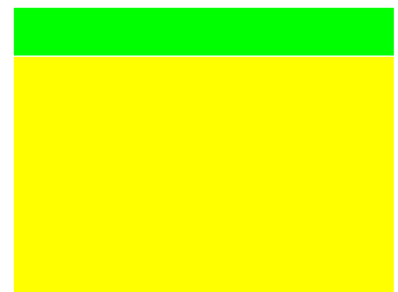
Schechter and JV, PRD **22** (1980) 2227

- 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

Ioannisian & J. V. PL B332 (1994) 93; Caldwell & Mohapatra; Joshipura; Bamert & Burgess; Balaji, Mohapatra, Parida & Paschos, Babu, Ma & JV, ...

Ellis & Lola, Ma, Casas et al, Haba et al, ...

leptonic CP violation

- will be a challenge !

  "Dirac" CPV suppressed, since ϕ disappears when $\Delta_{12} \to 0$

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

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

  Doi et al 1981, Wolfenstein PLB107

- but absent when large "Majorana"-masses are involved, such as leptogenesis

- REMARKABLE SEESAW CONNECTION

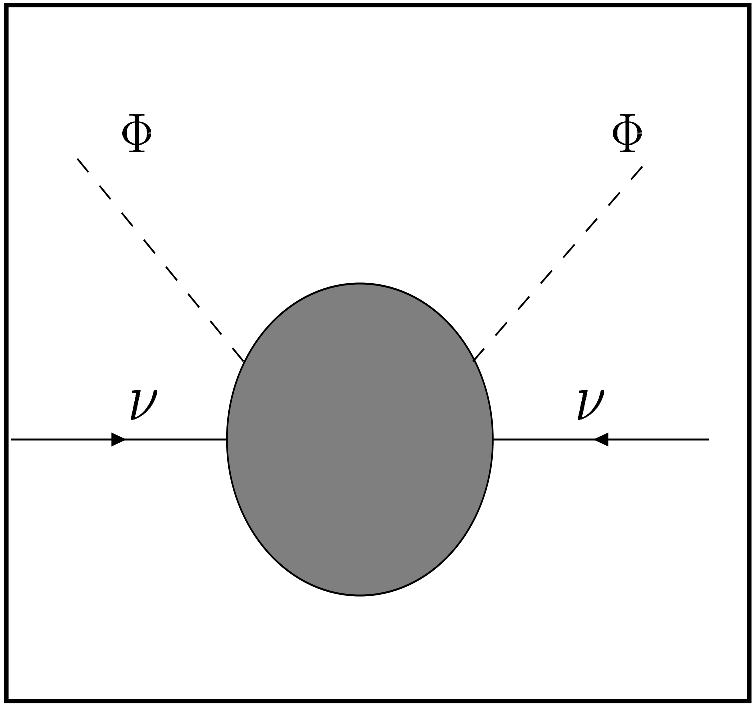
Theory ideas

Joe also pioneered gauge modelling of neutrino mass, e.g.

use of triplets to generate m_ν
the seesaw mechanism
and the lepton mixing matrix

Schechter, JV PRD **22** (1980) 2227 and D **25**, 774 (1982)

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

old but unfamiliar seesaw features

Schechter, JV, 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 θ_{ij} and CP violating phases ϕ_{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 JV, PRD **21** (1980) 309

Pathways to Neutrino Mass

- 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**

Thank you Joe

for your love for physics
for your modesty and integrity