Standard and non-standard neutrino properties

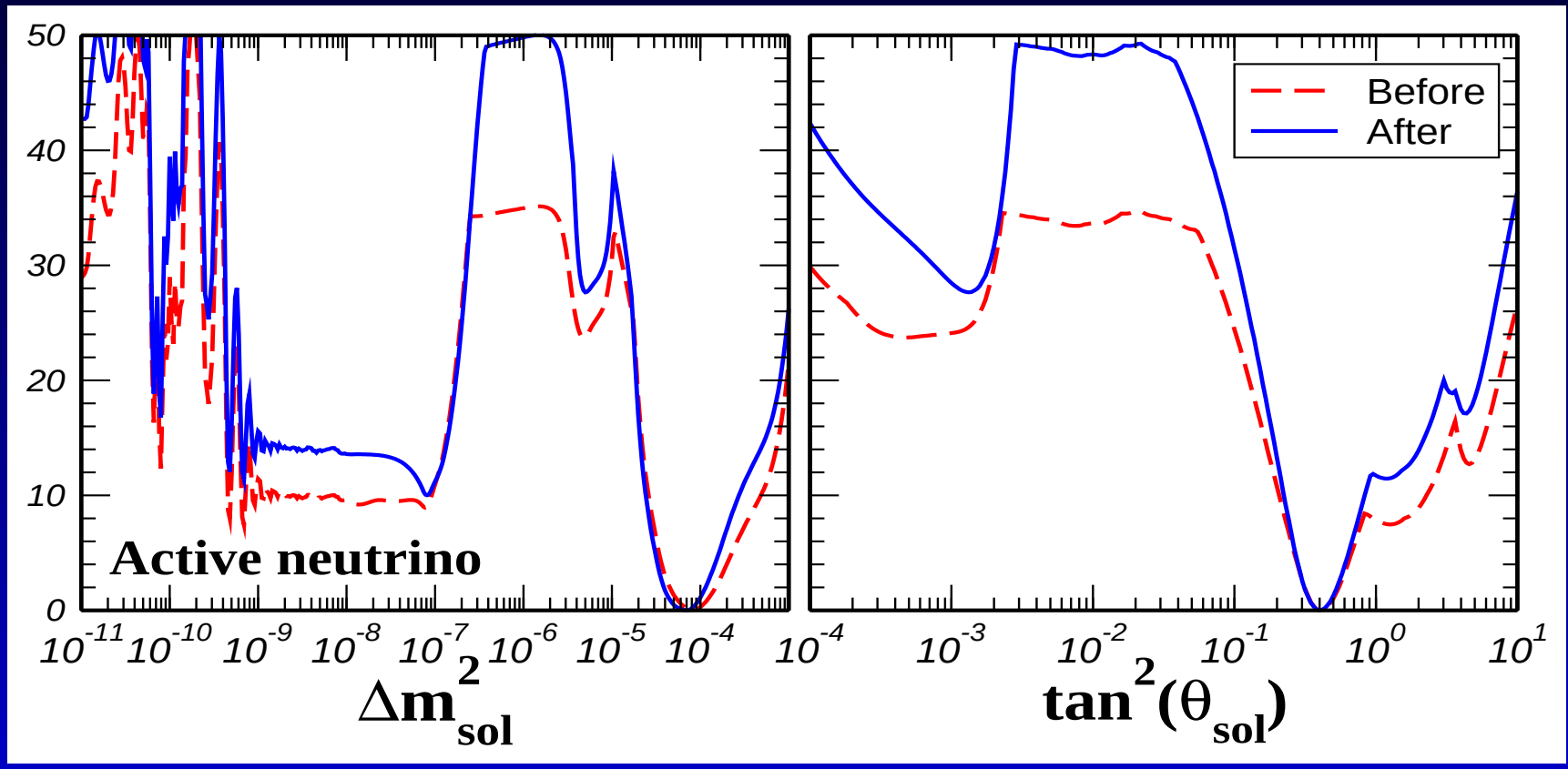
J. W. F. Valle

- masses and mixings
- from current oscillation experiments
- ... from first principles ...
- neutrinos as astrophysics probe
- Majorana, not Dirac
- Non-Standard nu-Interactions
- robustness of atmospheric oscillations
- other solar neutrino solutions
- The future

solar nu's before & after SNO-NC

more

Maltoni, Schwetz, Tórtola & JV, hep-ph/0206xxx



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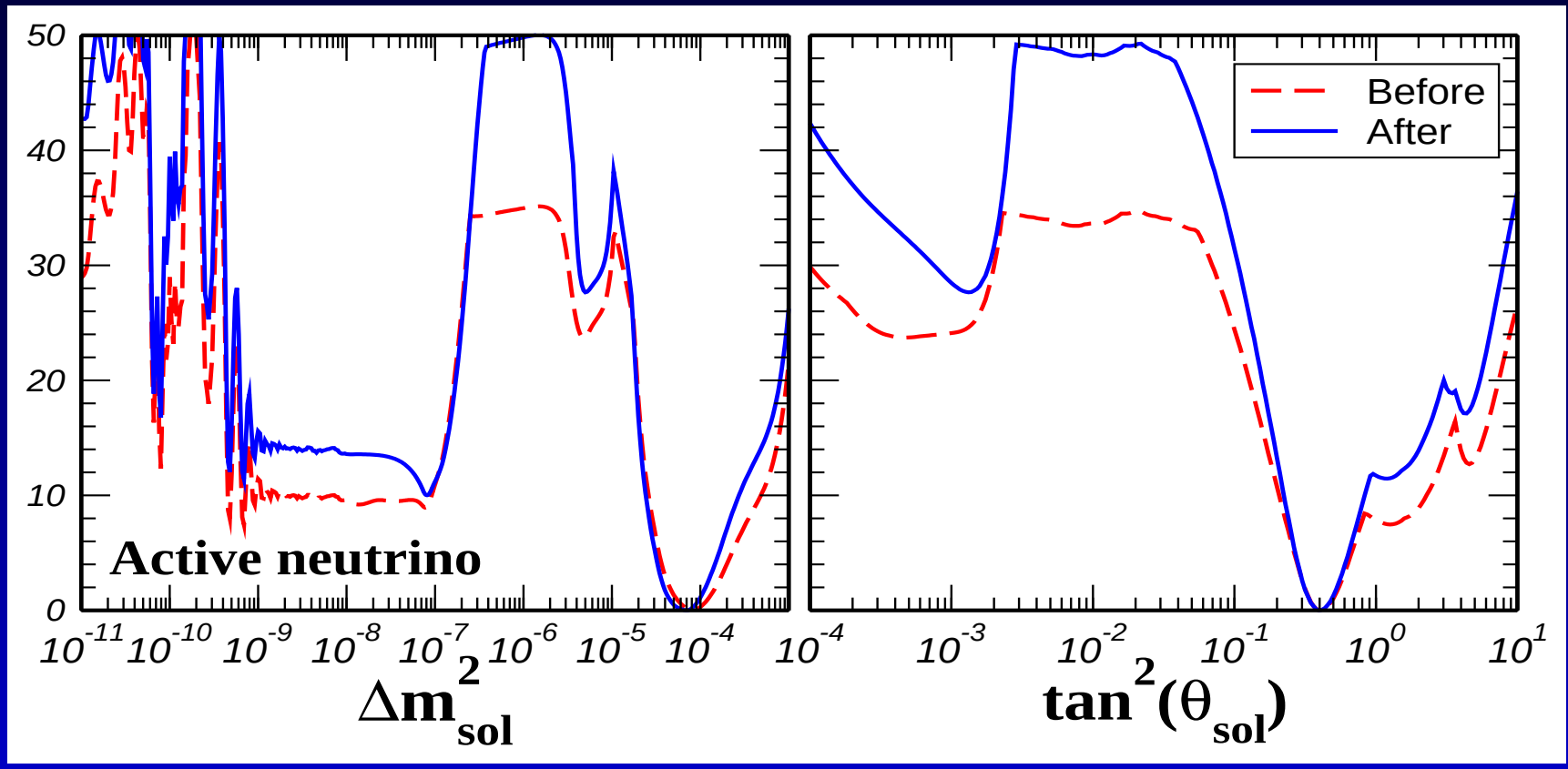


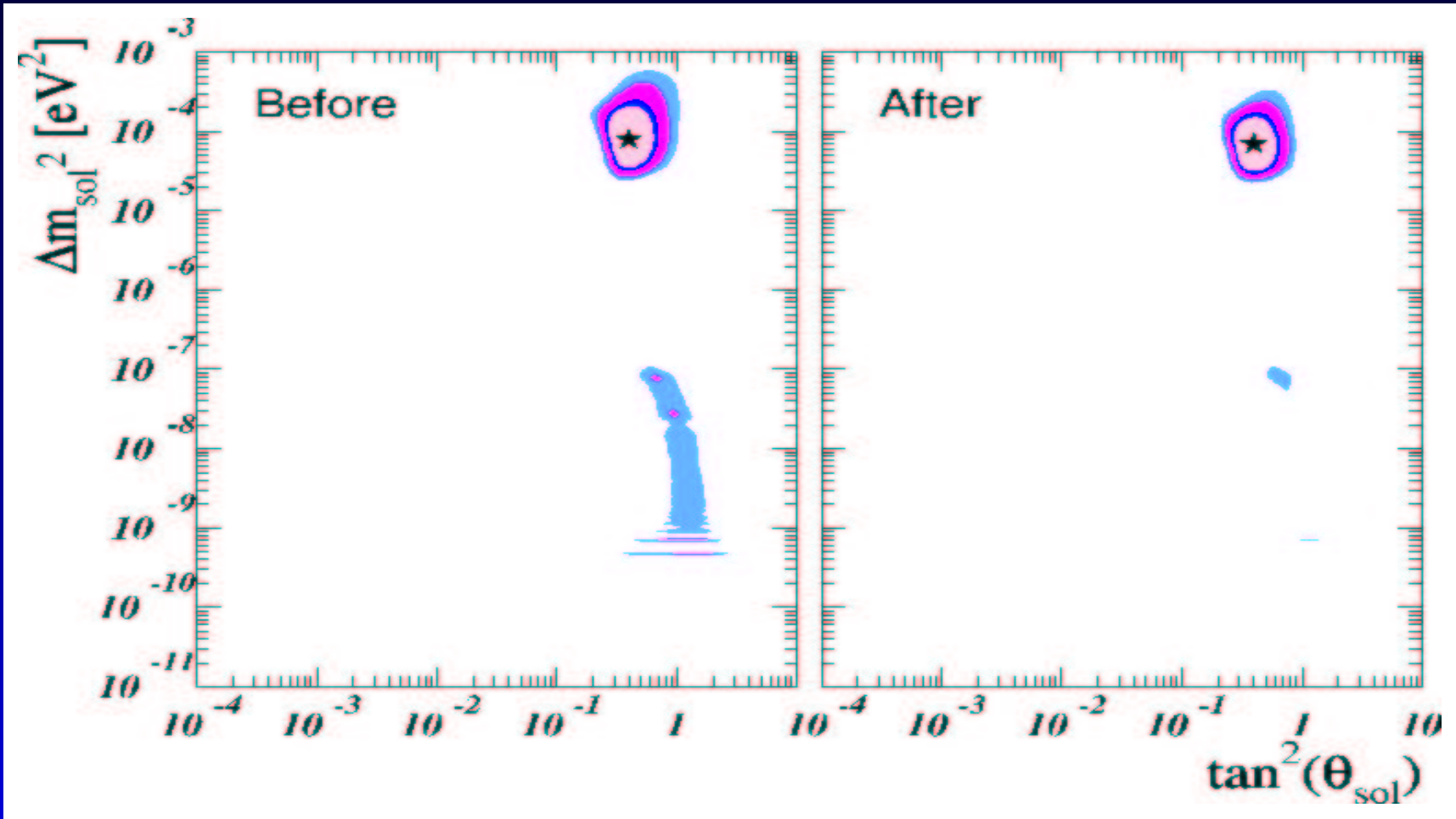
- good determination of both Δ_S and θ_S

first LMA hint from SK-spec Gonzalez-Garcia etal NPB573 (2000) 3

Lisi, Smirnov & Smy's talks; Bahcall et al; Bandyopadhyay et al; Barger et al; Creminelli et al

solar-nu oscillations-a

Maltoni, Schwetz, Tórtola & JV 2002



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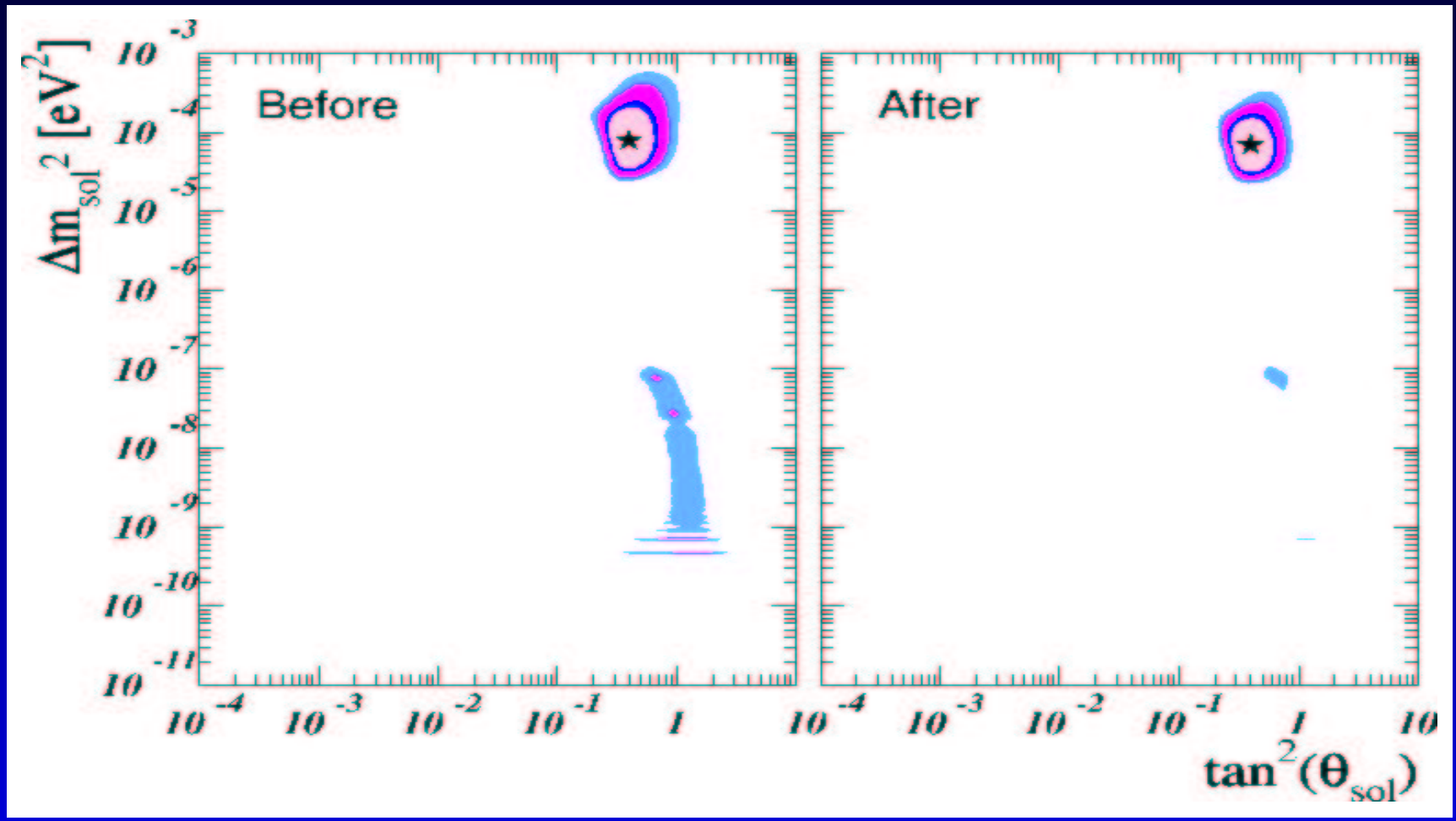
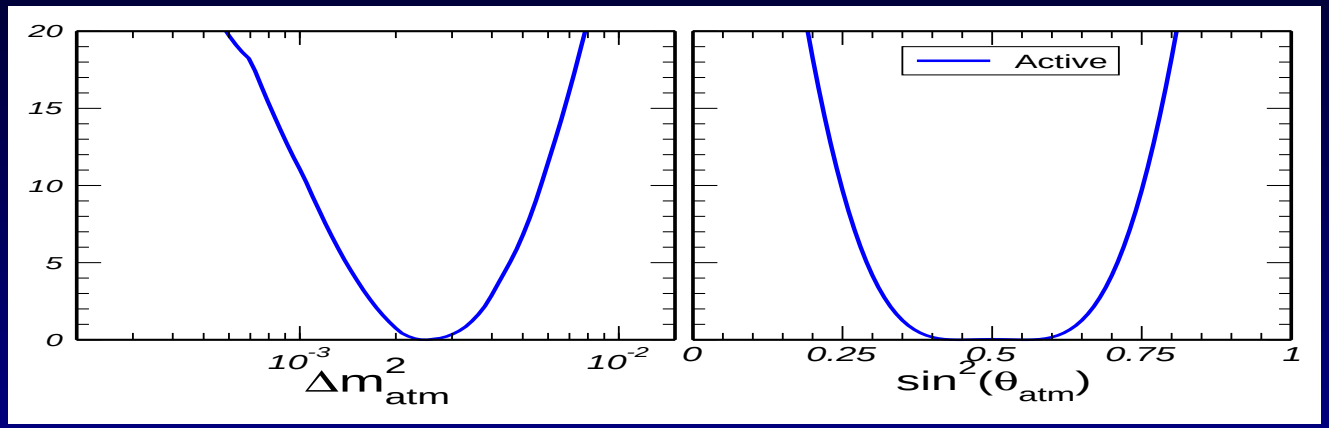


pure sterile disfavored at $\gtrsim 5\sigma$

reactor + atm neutrino oscillations

Fogli etal; Fornengo et al PRD65 (2002) 013010 Maltoni, Schwetz, Tórtola, JV 2002



$\sin^2 \theta_R \leq 0.045$ at 99% CL 1dof

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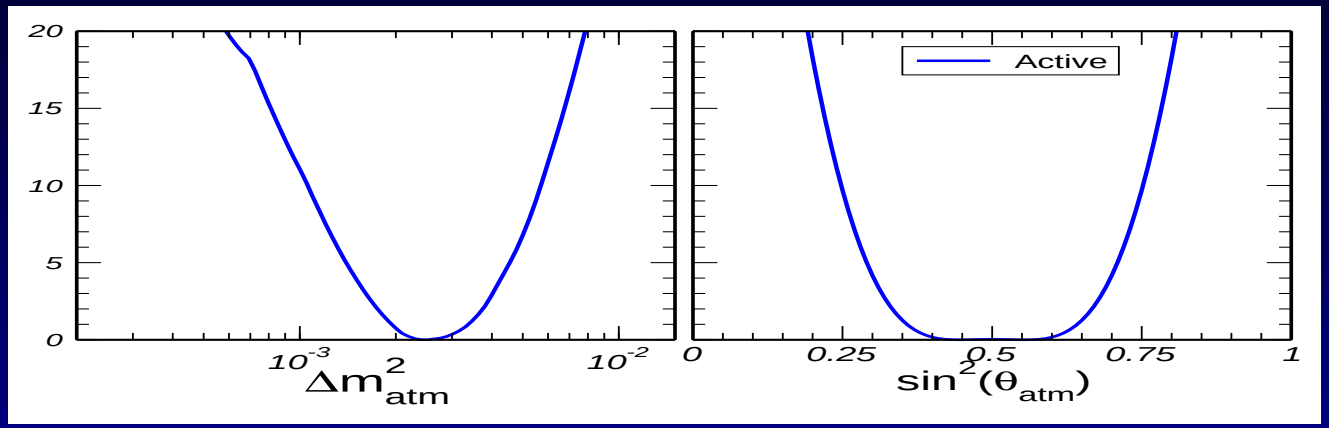

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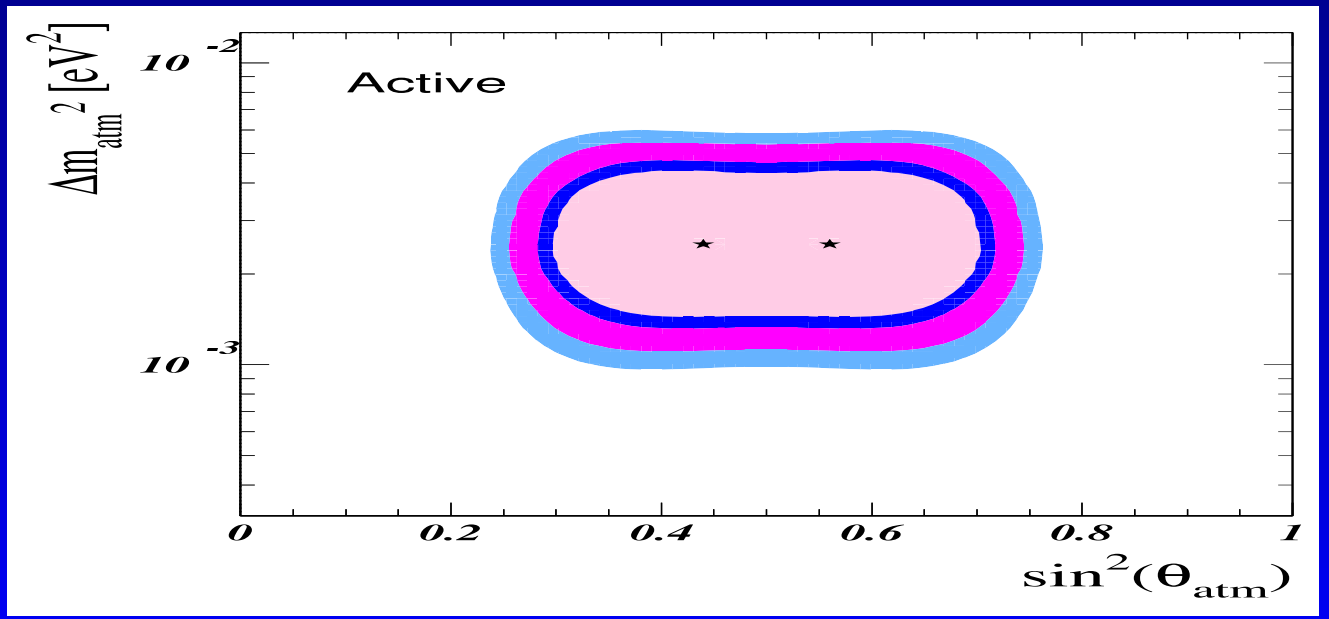

simplest gauge theory mixing matrix

- 3 angles θ

  1 KM-like

  + 2 extra phases + ...

23=A 12=S 13=R

ϕ_R

ϕ_1 , ϕ_2

Schechter, JV PRD22 (1980) 2227

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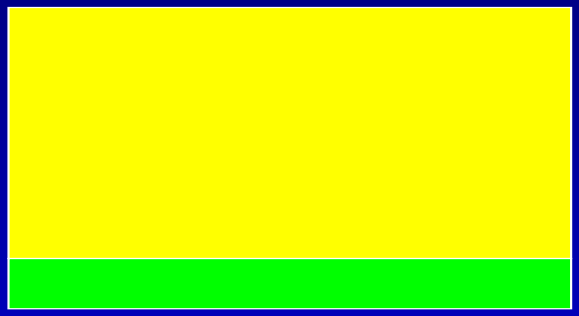
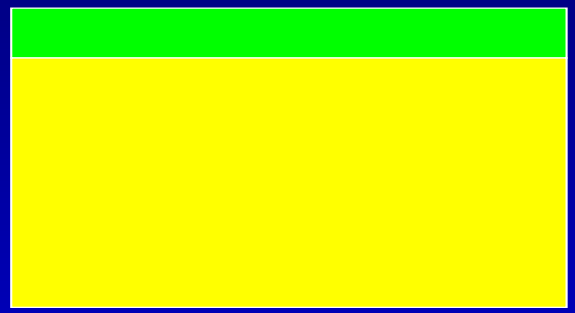
Schechter, JV PRD22 (1980) 2227

- max θ_A, large θ_S & small θ_R hierarchical splittings

N 

I 

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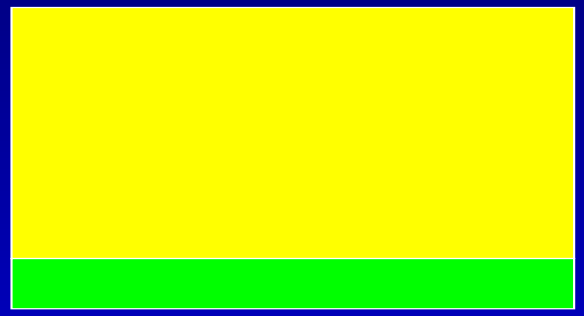

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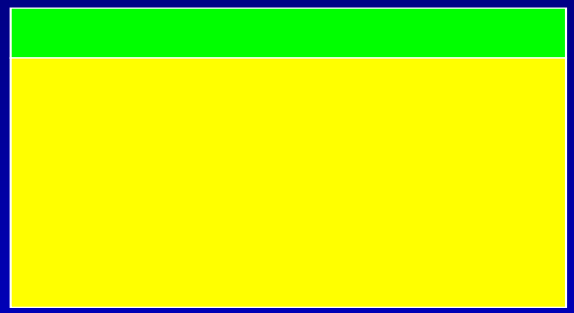


I

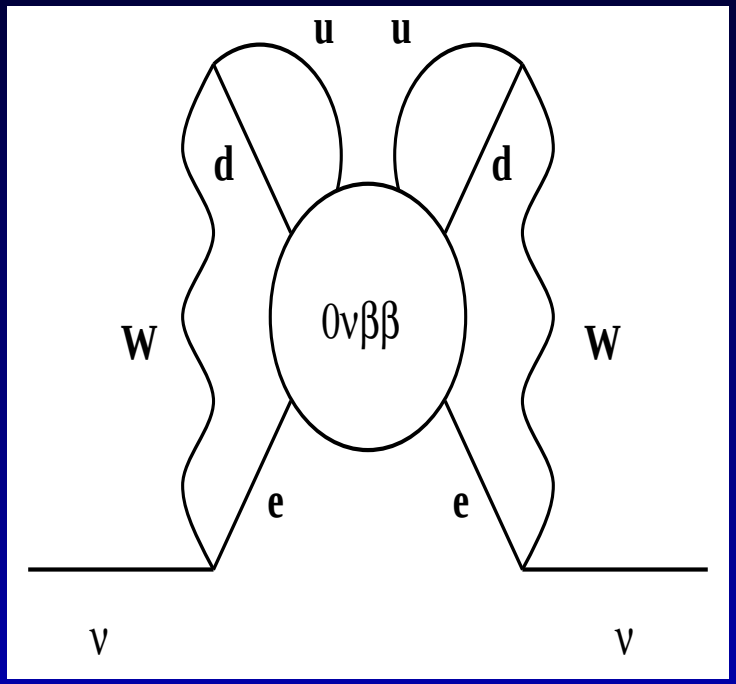
- leptonic CPV will be a challenge !

  "Dirac" CPV disappears when $\Delta_S \to 0$ PRD21 (1980) 309

  "Majorana" CPV suppressed due to V-A PRD23 (1981) 1666

Dirac or Majorana?

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



Schechter, JV PRD25 (1982) 2951

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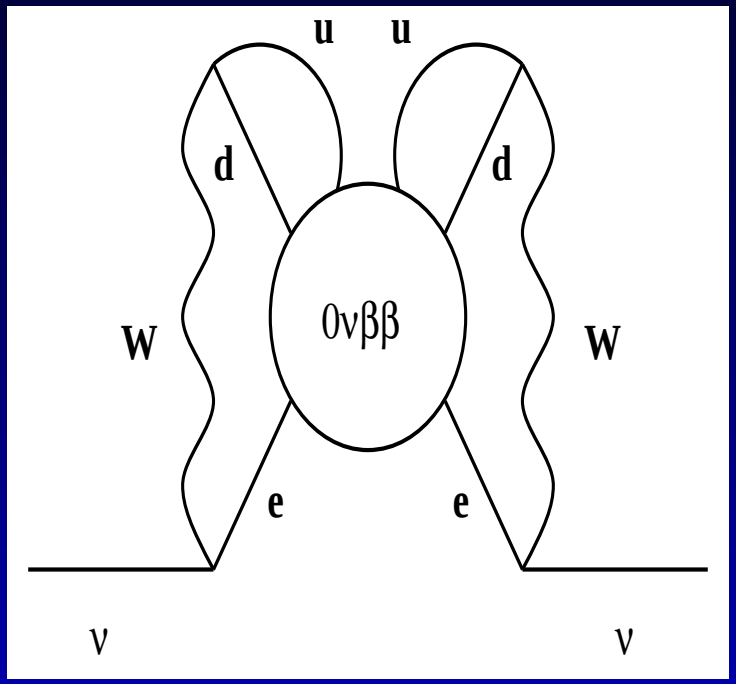
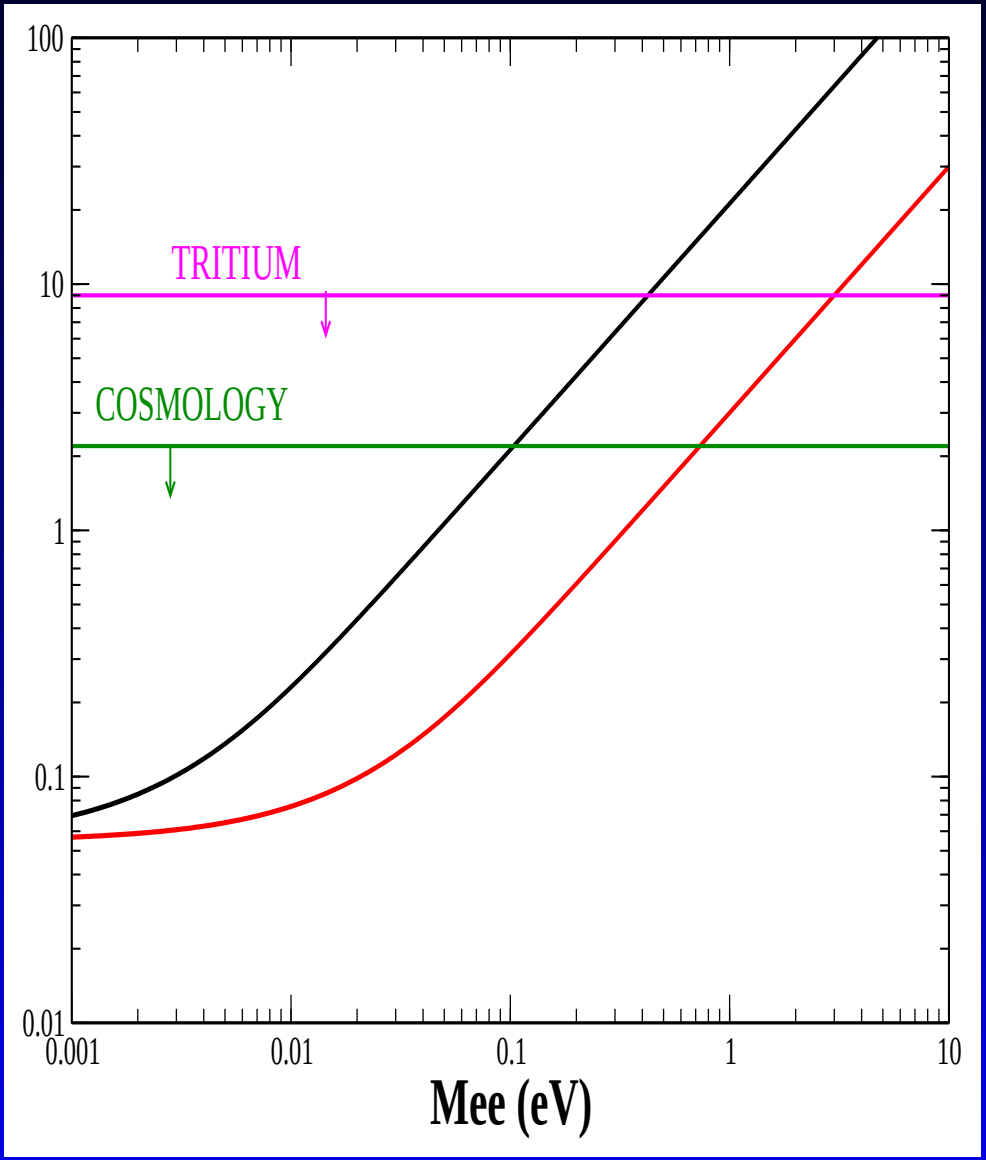


Schechter, JV PRD25 (1982) 2951

- like other $\Delta L = 2$ processes (e.g. nu-transition magnetic moments) $\beta_{0\nu}$ is sensitive to Majorana phases
  Schechter & JV D24 (1981) 1883; Wolfenstein PLB107 (1981) 77; Doi et al; Bilenky et al, Kayser et al

absolute neutrino mass scale



Barger et al PLB532 (2002) 15

neutrinos as astro probe

- large angle oscillations affect $\bar{\nu}_e$ SN-signal

  Smirnov, Spergel, Bahcall 94; Raffelt et al 96, Kachelriess et al JHEP 0101 (2001) 030

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- solar+SN1987A analysis

  Kachelriess et al PRD65 (2002) 073016

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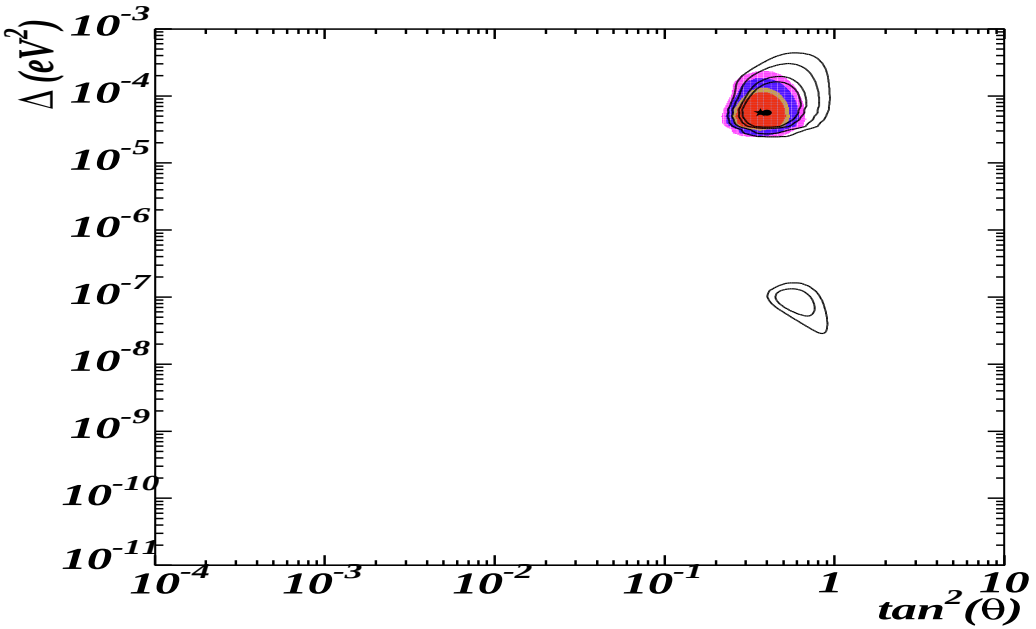
  Kachelriess et al PRD65 (2002) 073016

- "standard" SN input, $E_{\bar{\nu}_e}$=14, $E_{\rm bind}$=3, $\tau \equiv T_{\nu_h}/T_{\bar{\nu}_e}$=1.4



thanks to Strumia

LMA may remain best

neutrinos as astro probe future SN

use effect of large mixing on $\bar{\nu}_e$ signal to probe $\tau \equiv T_{\nu_h}/T_{\bar{\nu}_e}$

Minakata, Nunokawa, Tomàs, J. V. hep-ph 0112160

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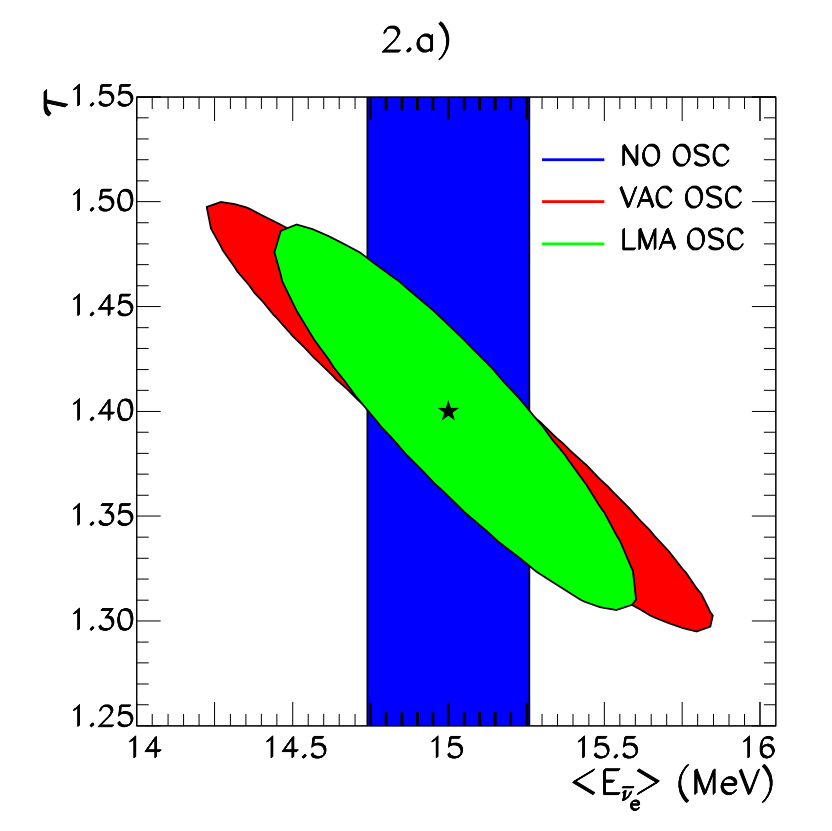

Compare LMA-LOW-VAC with no-oscillation

assume SK detector and 10 kpc gal SN, simulate data with given $\langle E^0_{\bar{\nu}_e} \rangle$, τ^0, E^0_b

oscillations from first principles

predicting nu-mass and mixing?

- what is the scale ?
  - Planck scale: Strings?
  - GUT scale $\mathrm{E}(6)$, $\mathrm{SO}(10)$,...
  - Intermediate scale: P-Q, L-R ...
  - Weak $\mathrm{SU}(3) \otimes \mathrm{SU}(2) \otimes \mathrm{U}(1)$ scale

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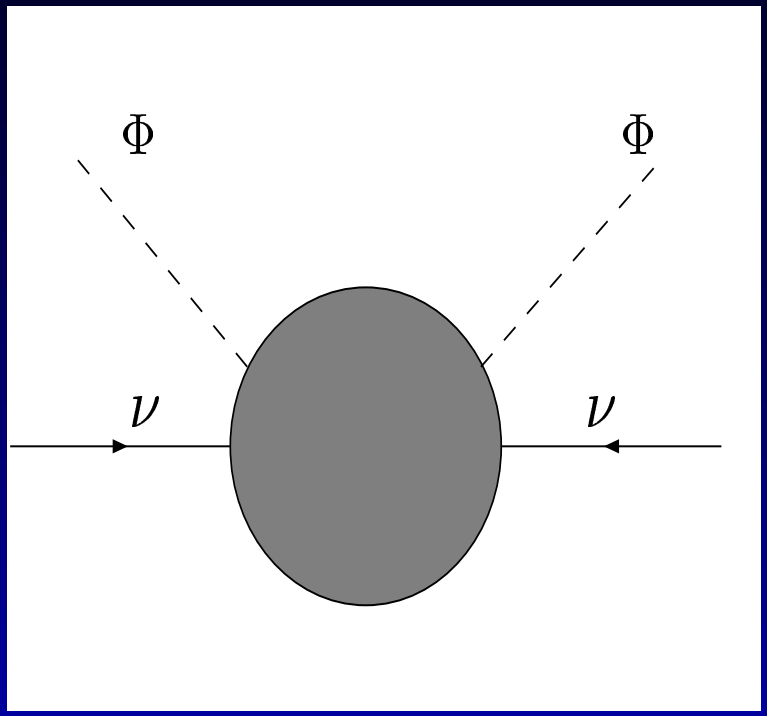
- no theory of flavour

neutrino mass theories

2 approaches: top-down and bottom-up

hierarchical vs quasi-degenerate spectra

basic dim-5 operator



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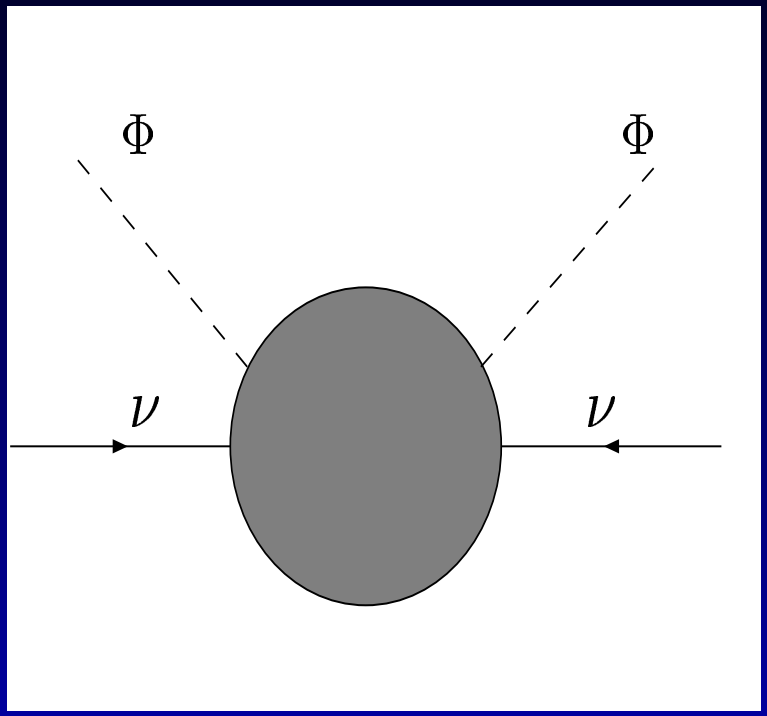

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Weinberg; Barbieri, Ellis, Gaillard; Akhmedov et al

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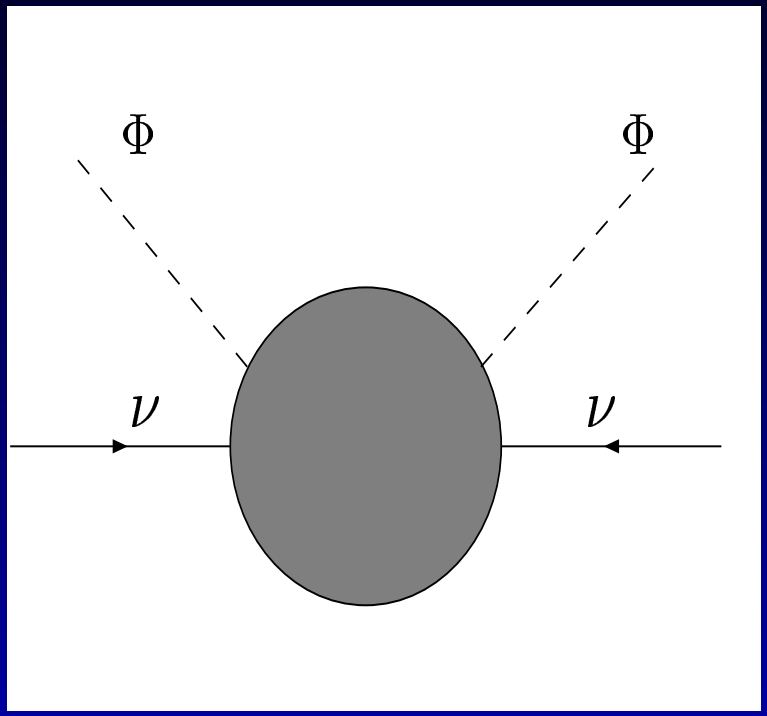


- from Gravity

Weinberg; Barbieri, Ellis, Gaillard; Akhmedov et al

- from seesaw schemes

Gell-Mann, Ramond, Slansky; Yanagida;

Mohapatra, Senjanovic; Schechter, Valle

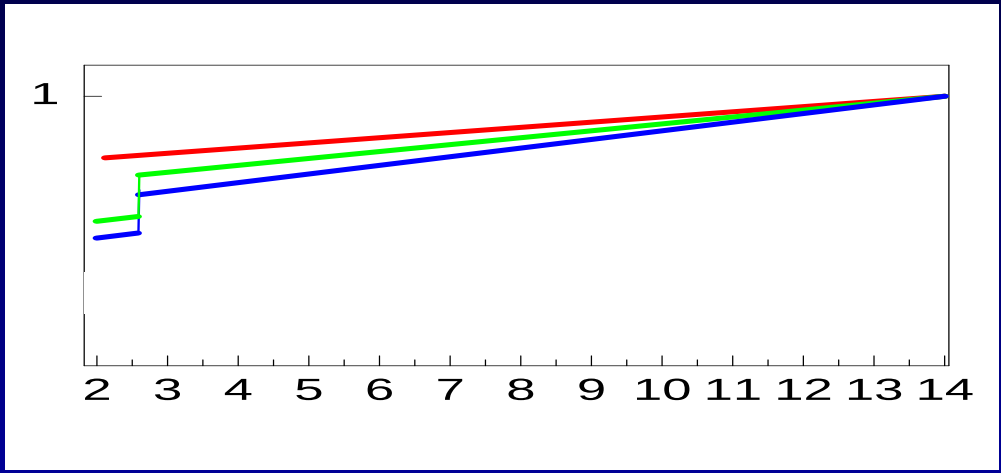
King's talk

here I consider at an effective level

neutrino unification

Chankowski, Ioannisian, Pokorski & JV PRL 86 (2001) 3488

- masses unify when they run upwards



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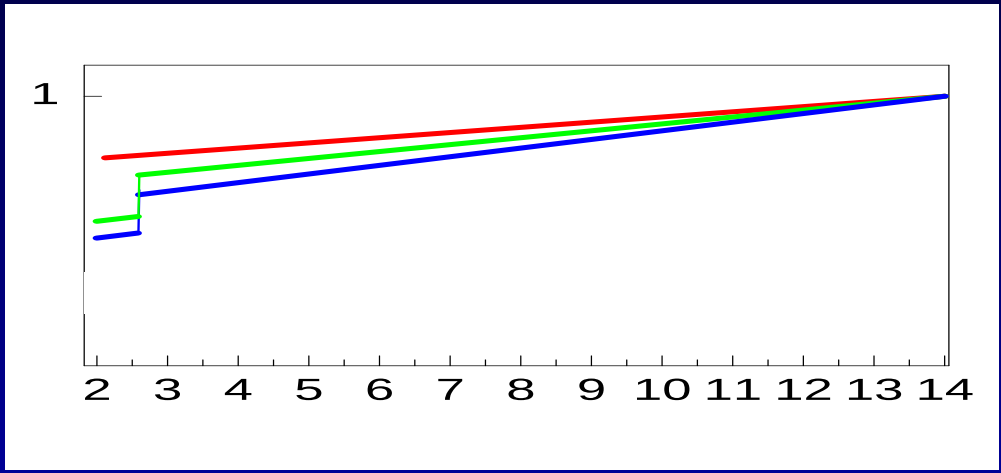

- common nu-mass at M_X, splittings from RGE

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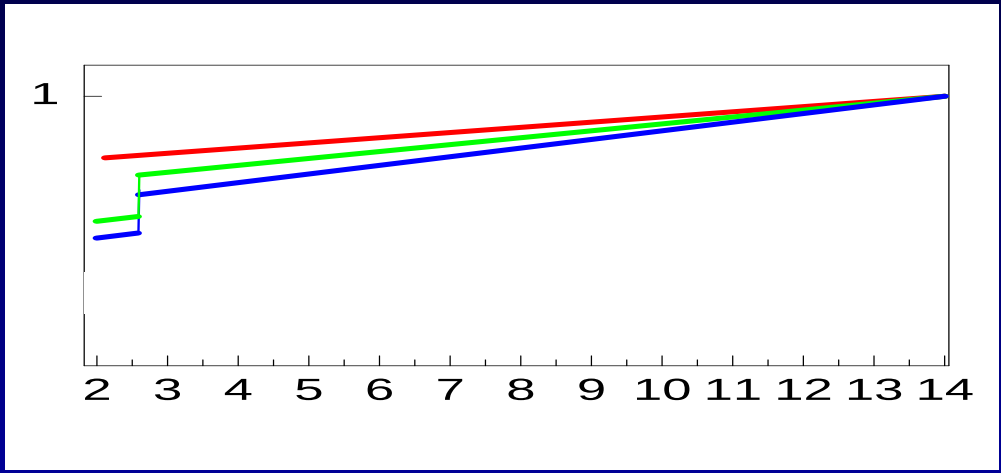

- common nu-mass at M_X, splittings from RGE
- large solar mixing predicted

  effects in β decay (KATRIN)
  and HDM (2dF galaxy redshift survey)
  but no $\beta_{0\nu} \rightarrow$ stable under RC **more**

family symmetries

Nardi et al PLB492 (2000) 81

quark and lepton mixing from textures

U(1) symmetry gives simplest bi-linear RPV SUSY model:

$W = W_{MSSM} + \mu_\alpha \ell_\alpha H_u$

giving common origin for μ-problem & nu-anomalies

$\mu_0 \sim m_{3/2}\theta$ Giudice-Masiero

$\mu_i \sim m_{3/2}\theta^{7+x}$ Nilles-Polonsky

2 massless nu's after RPV-seesaw degeneracy lifted by loops

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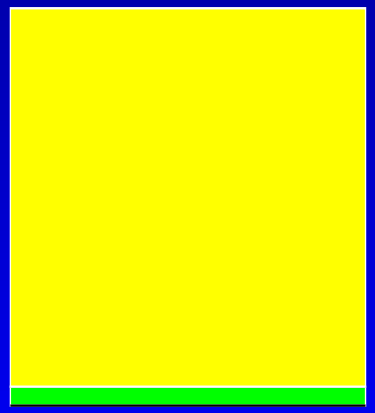

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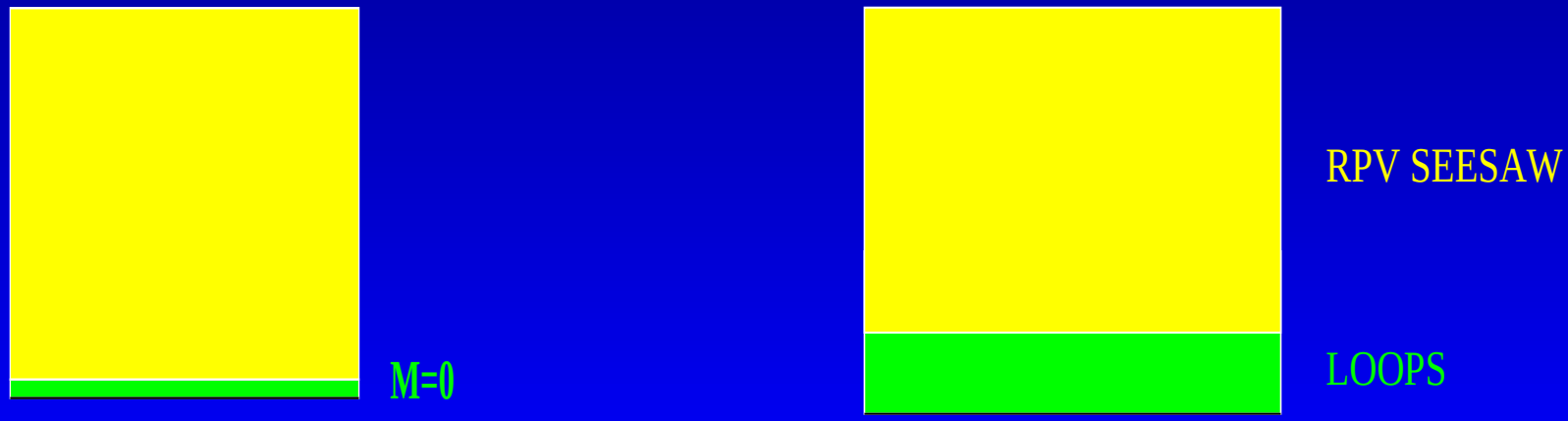

RPV as origin of neutrino masses

Aulakh, Mohapatra 83; Hall, Suzuki 84 ; Ross, JV 85; Ellis et al 85; Santamaria, JV 87, . . .

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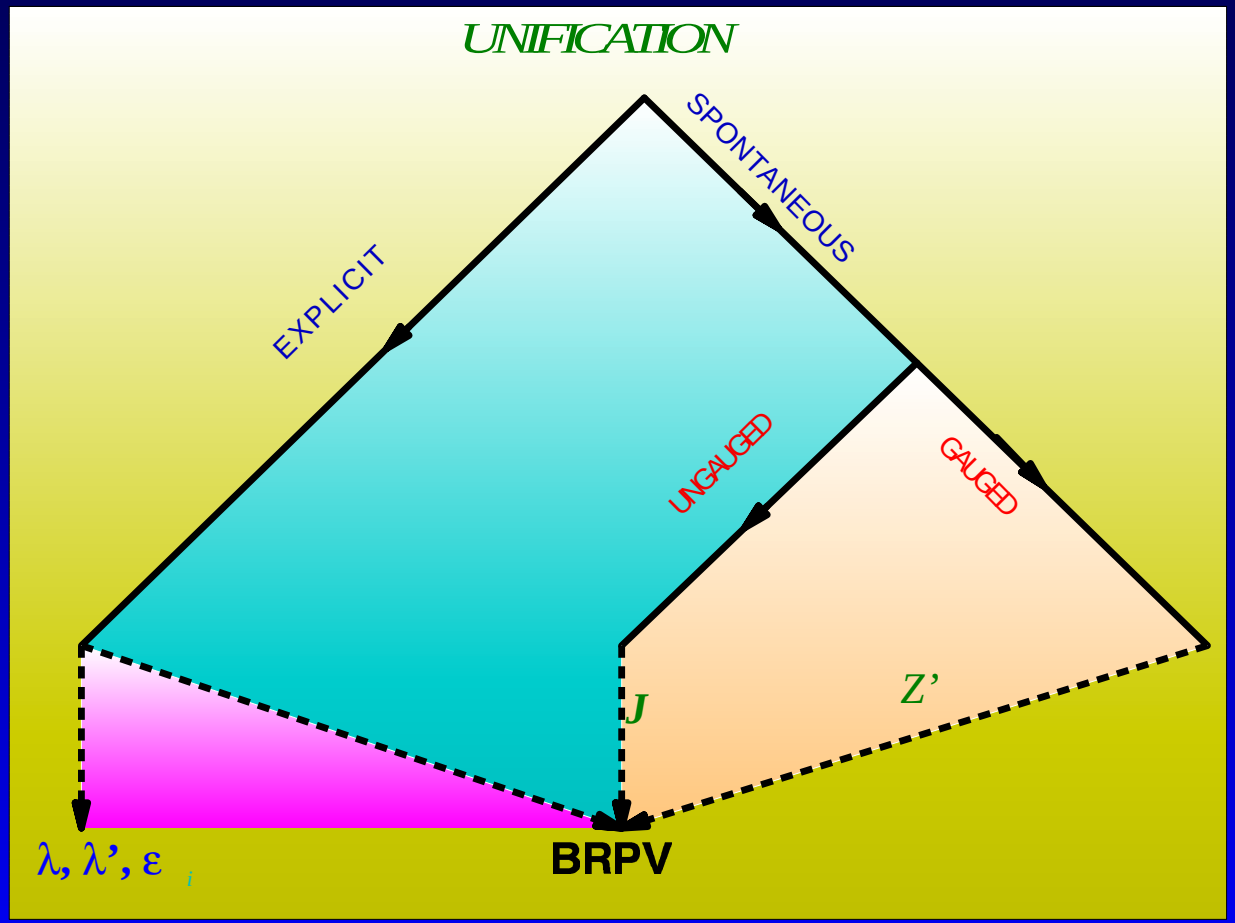
Aulakh, Mohapatra 83; Hall, Suzuki 84 ; Ross, JV 85; Ellis et al 85; Santamaria, JV 87, . . . various realizations



BRPV soln to nu-anomalies

Hirsch et al PRD62 (2000) 113008 & PRD61 (2000) 071703

- arises automatically if RPV spontaneous

Masiero, JV PLB251 (1990) 273 more...

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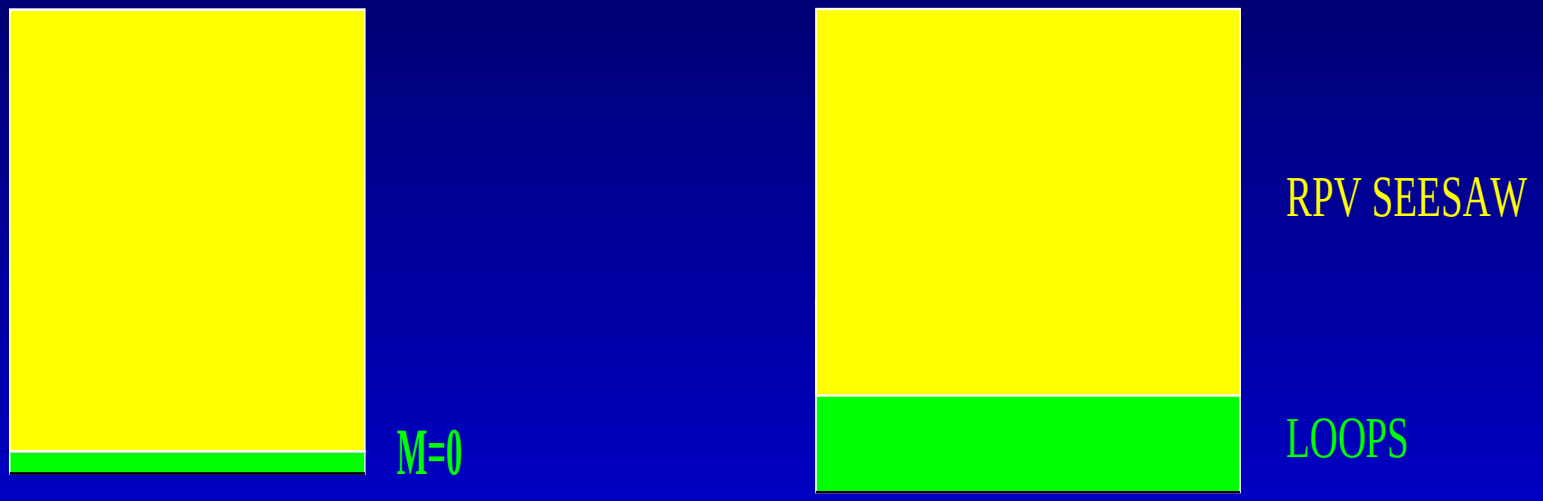
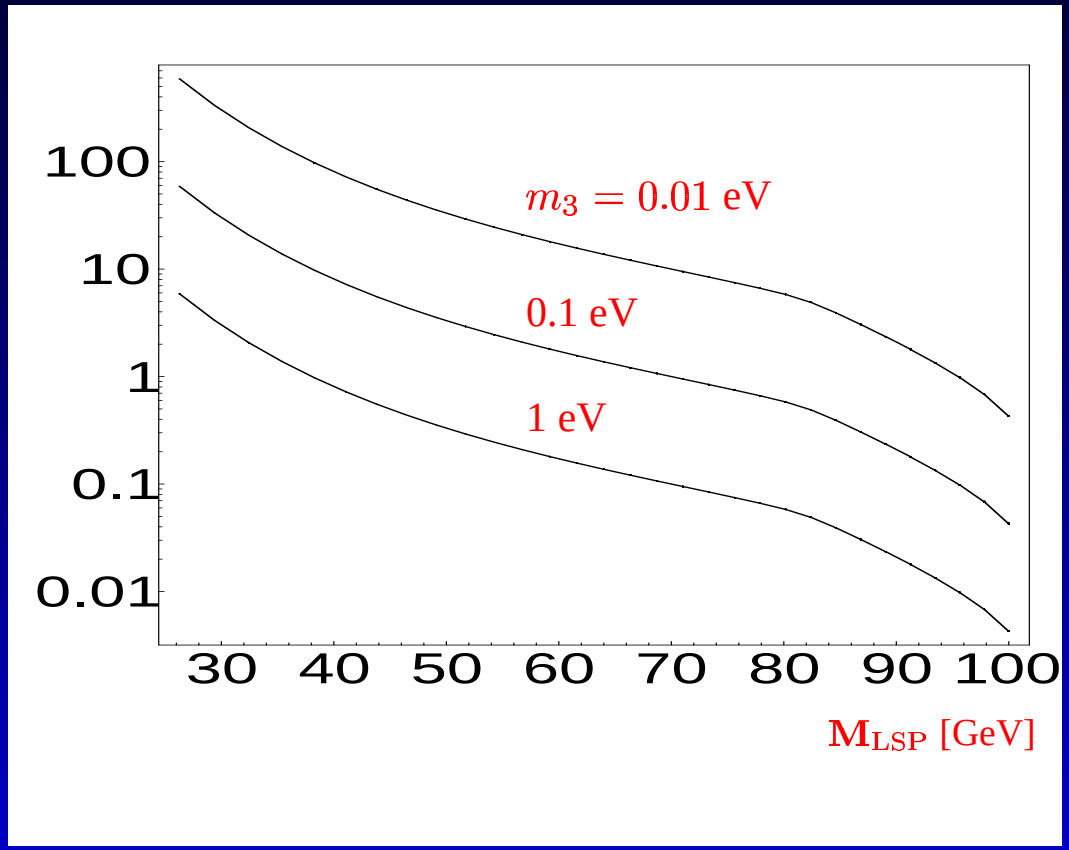
- hierarchical nu-masses



LSP decay length [cm]: BRPV

from Bartl et al NPB 600 (2001) 39

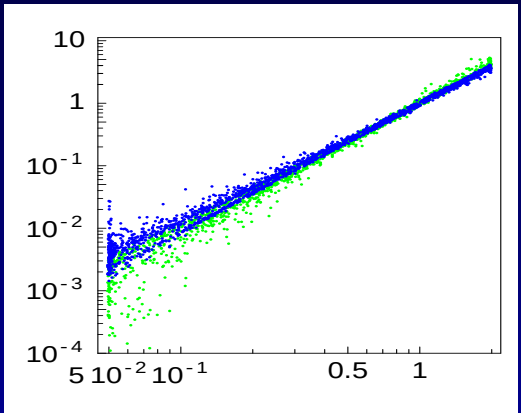


Mukhopadhyaya, Roy & Vissani; Chun & Lee; Choi et al; Datta et al

neutrino mixing angles in BRPV

Hirsch et al PRD62 (2000) 113008

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



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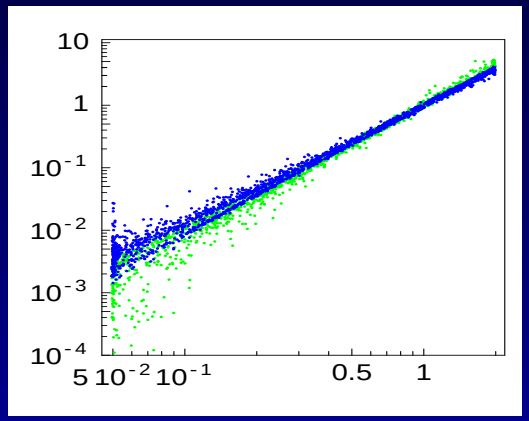
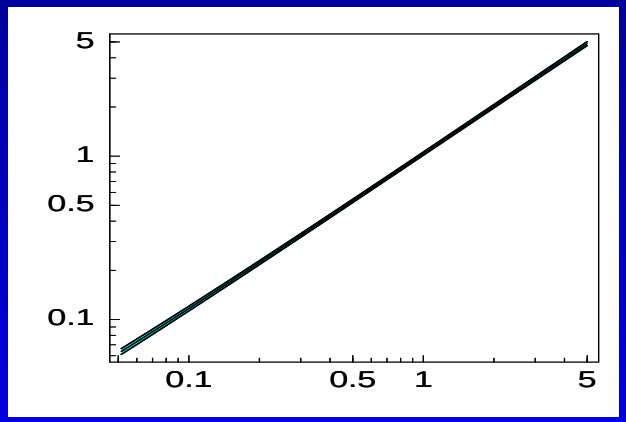


tested in Sparticle decays

LSP decays probe ATM $\frac{\chi \to \mu qq}{\chi \to \tau qq}$ Porod etal PRD63 (2001) 115004



Stop decays trace SOL Restrepo et al PRD64 (2001) 055011

Life beyond LMA ??

Non-standard interactions

- not a sin more

Non-standard interactions

- not a sin more
- dim-4 renormalizable (eg CC & NC)

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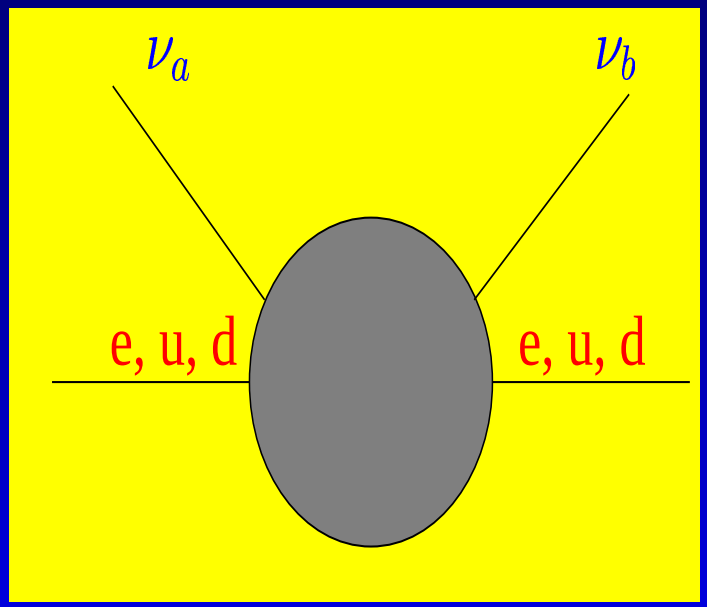


- affect nu-propagation

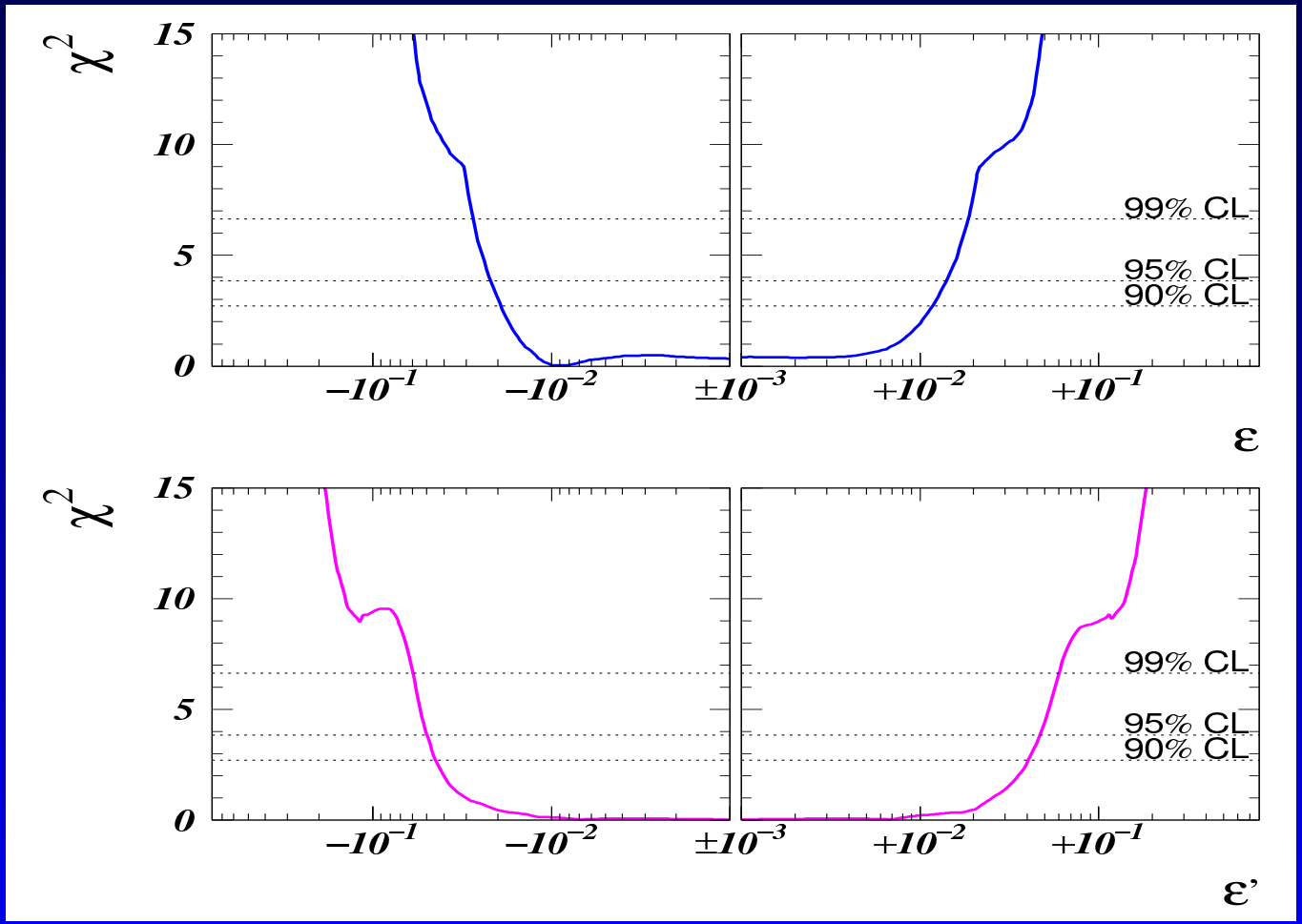
more... good atm-contained fit G-G et al PRL82 (1999) 3202

How robust are Oscillations ??

atmospheric bounds on NSI

Fornengo, Maltoni, Tomàs & J. V. PRD65 (2002) 013010

bounds on FC and NU nu-interactions



alternatives to (solar-nu) oscillations?

at least two viable ones ...

Spin Flavor Precession

over 20 years

Schechter, Valle PRD24 (1981) 1883, PRD25, 283

add matter effects

Lim-Akhmedov-Marciano (1988) PRD37, 1368; PLB213, 64

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Density & B-field profiles

from Miranda etal NPB595 (2001) 360, PLB521 (2001) 299

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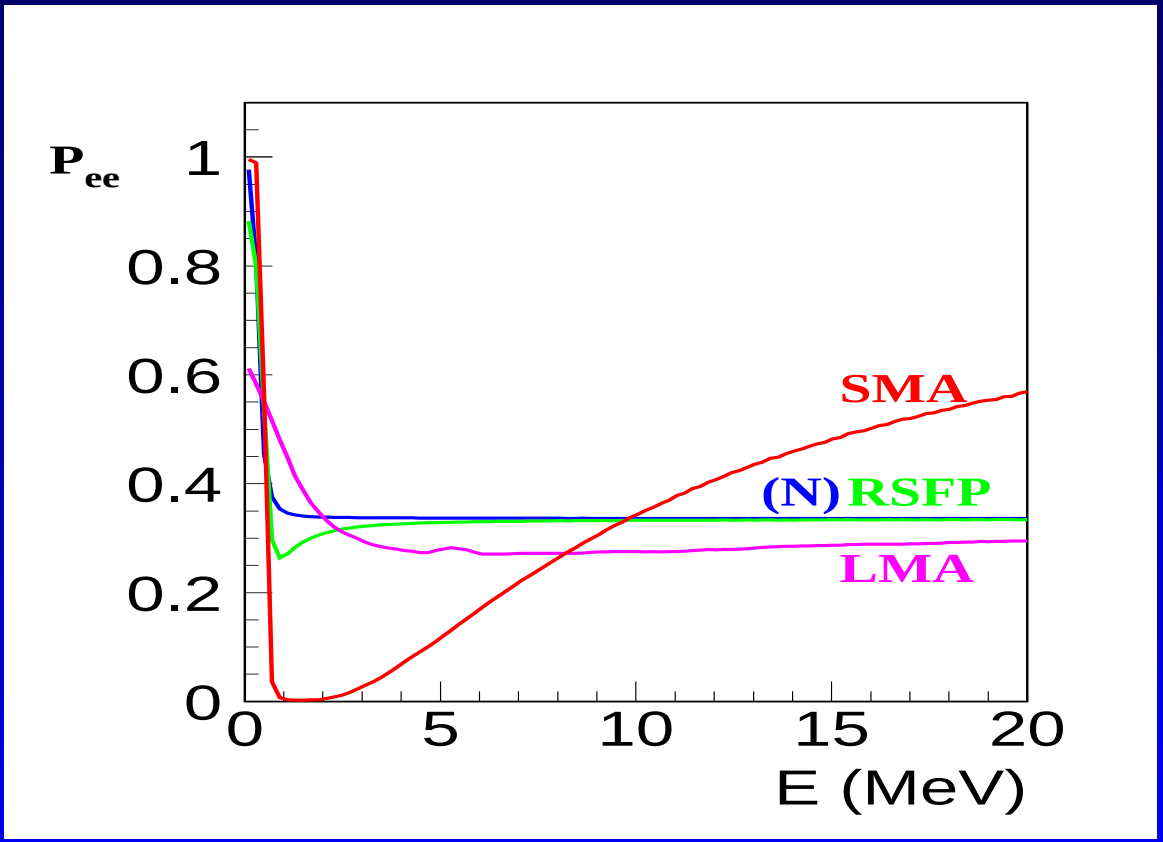
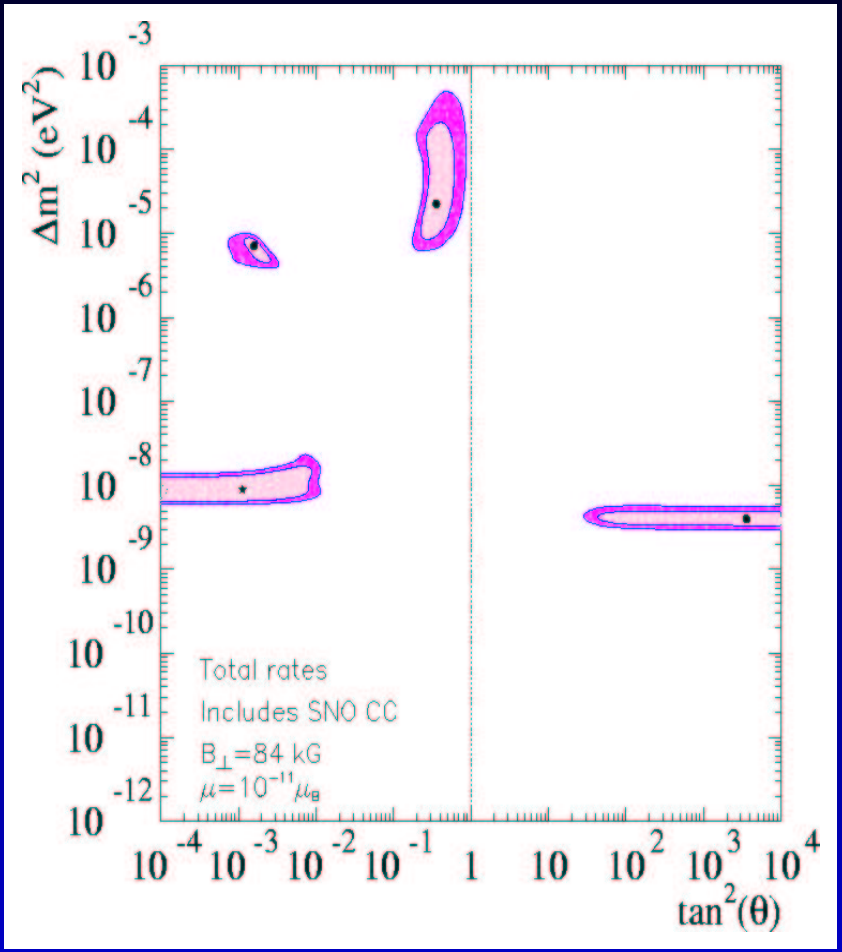


more

Oscillation-SFP

Miranda etal PLB521 (2001) 299



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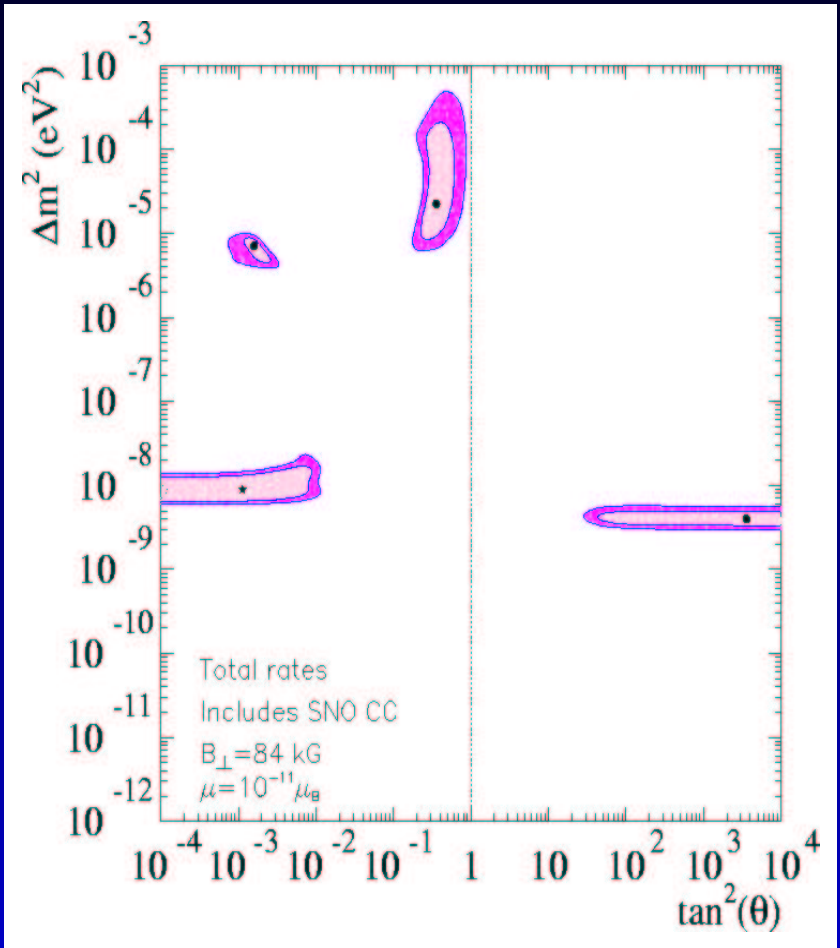
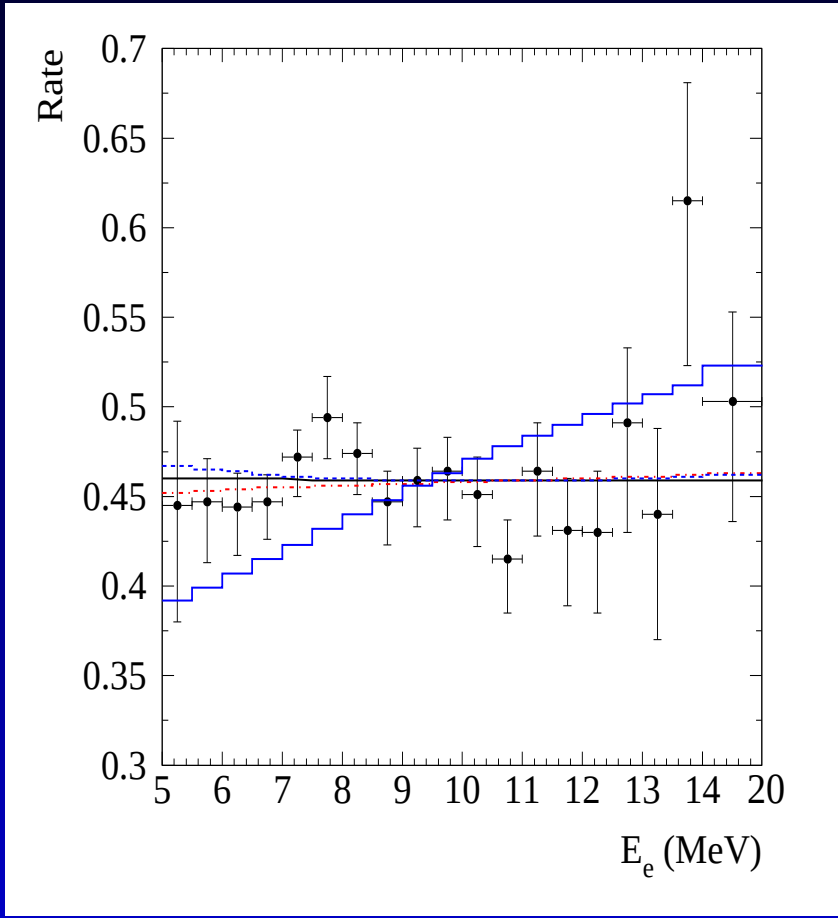
Miranda etal PLB521 (2001) 299



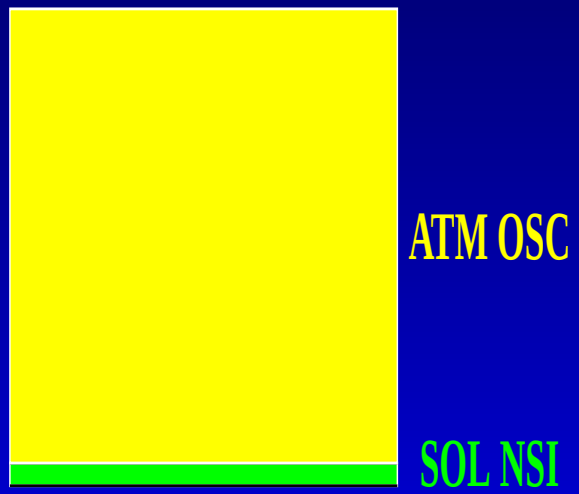


only 3 good solns: RSFP, NRSFP & LMA

expected Borexino signal lower than for LMA Akhmedov & Pulido

hybrid NSI soln to nu-anomalies

post-SNO-NC global fit upd of Guzzo et al NPB629 (2002) 479



no solar splitting nor mixing needed

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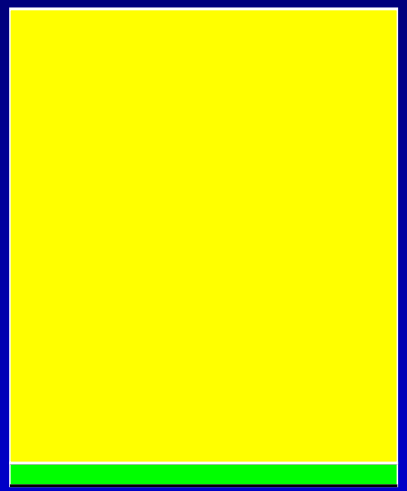

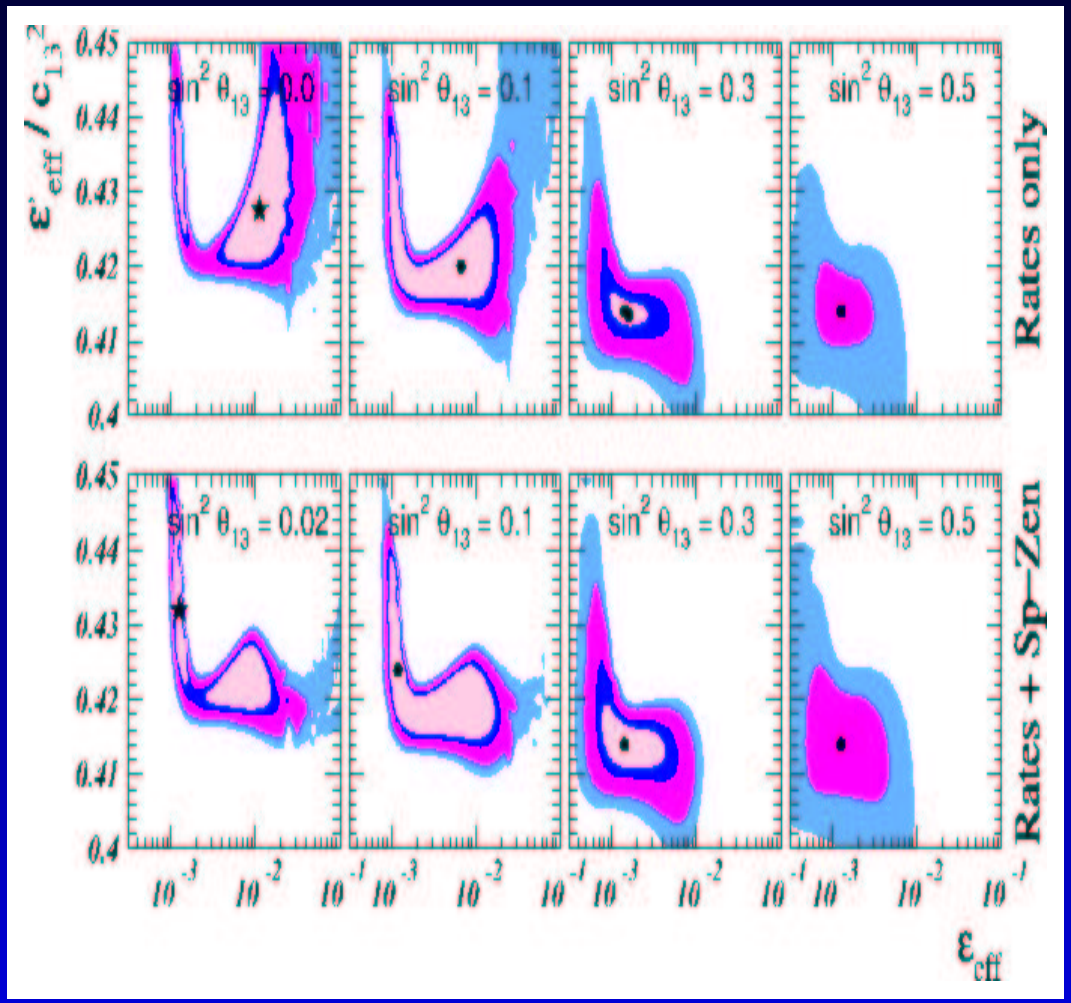

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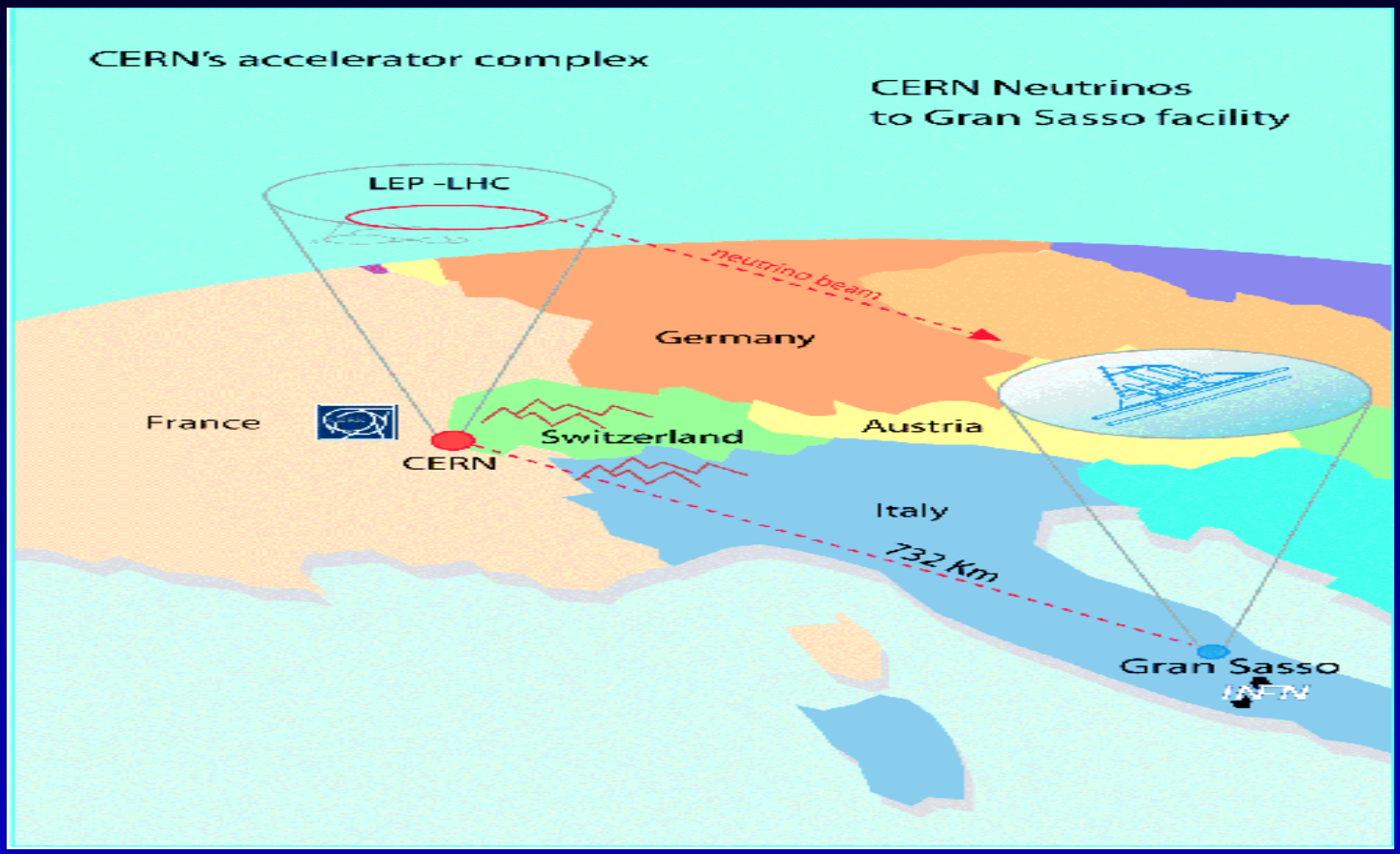
oscillation studies at NuFact



Dydak's and Lindner's talks

oscillation studies at NuFact

apart from probing s_{13} and δ ...

NuFact can and must probe NSI — Huber et al

Improved FC-tests — PLB523 (2001) 151

confusion theorem — PRL88 (2002) 101804

hep-ph/0202048

adding LSND: 4-nu models

Peltoniemi, Tommasini & JV PLB298 (1993) 383

Peltoniemi & JV NPB406 (1993) 409

Caldwell-Mohapatra PRD48 (1993) 325

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

more

light sterile-nus from extra dimensions

Ioannisian, JV PRD63 (2001) 073002

Antoniadis, Arkani-Hamed, Dimopoulos, Dvali... Mohapatra, Perez-Lorenzana...

- sterile-nu as zero-th mode of the Kaluza-Klein tower

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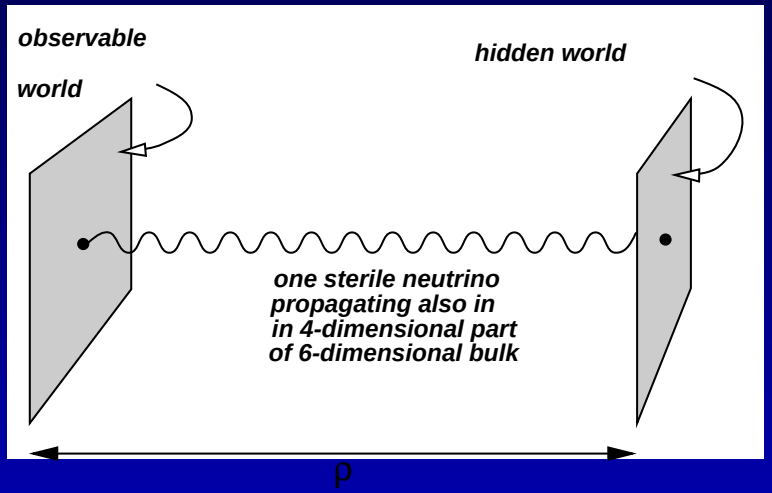

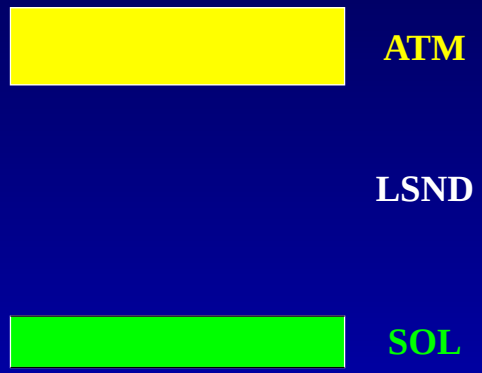

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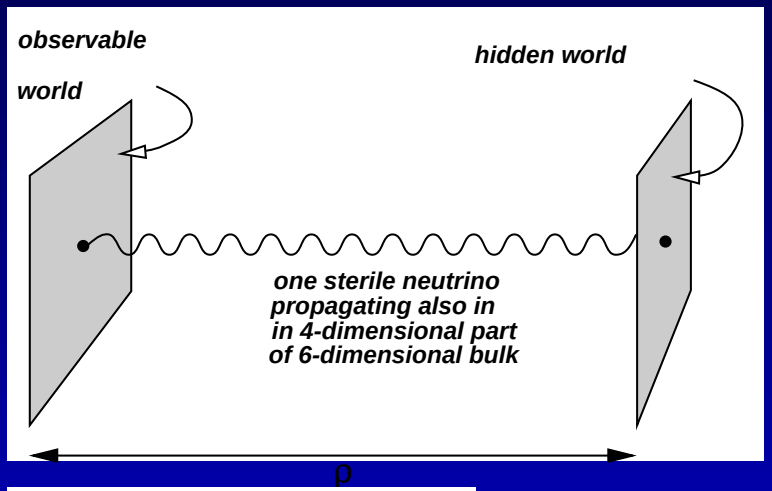

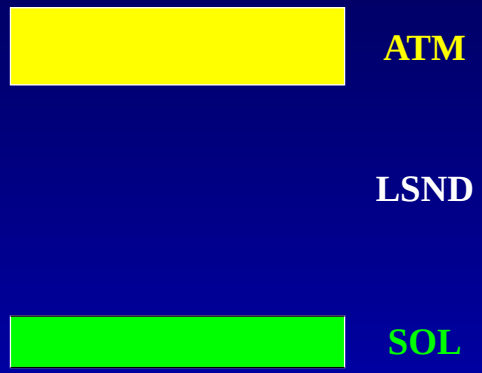

- $m_\nu = (\frac{M_F}{M_{\rm P}})^{\frac{\delta}{n}} m_f$ $\quad M_F \sim$ TeV $\quad \delta = 4 \quad n = 6$

volume suppression vs symmetry protection ...

light sterile-nus from extra dimensions

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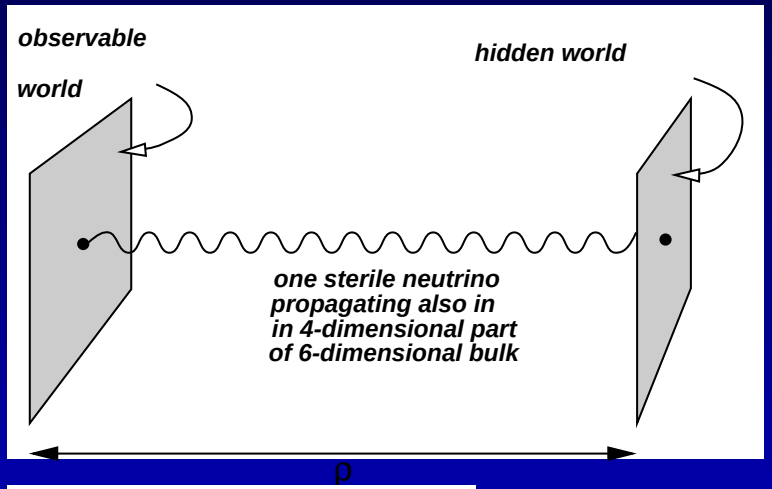

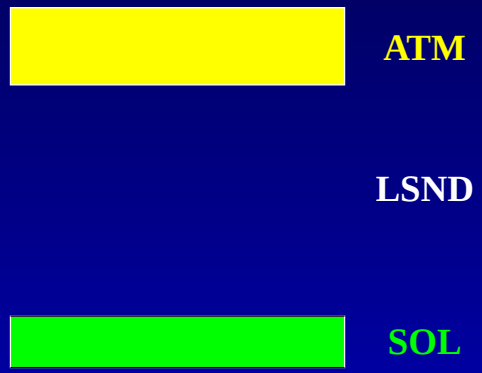

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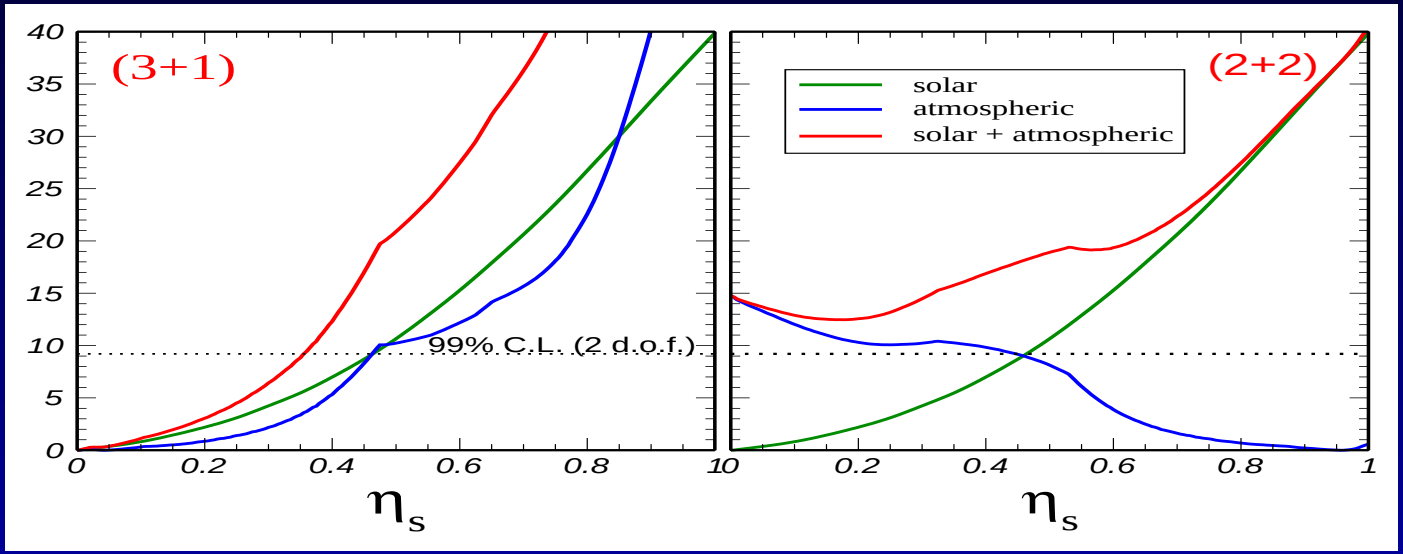
- atm & solar scale from RPV Hirsch, JV PLB495 (2000) 121

  or radiative Peltoniemi, Tommasini, JV PLB298 (1993) 383

  $\theta_A \sim \pi/4$ predicted

sterile-nu after SNO-NC Schwetz's poster

Maltoni, Schwetz, Tórtola & JV; upd of PRD65 (2002) 093004



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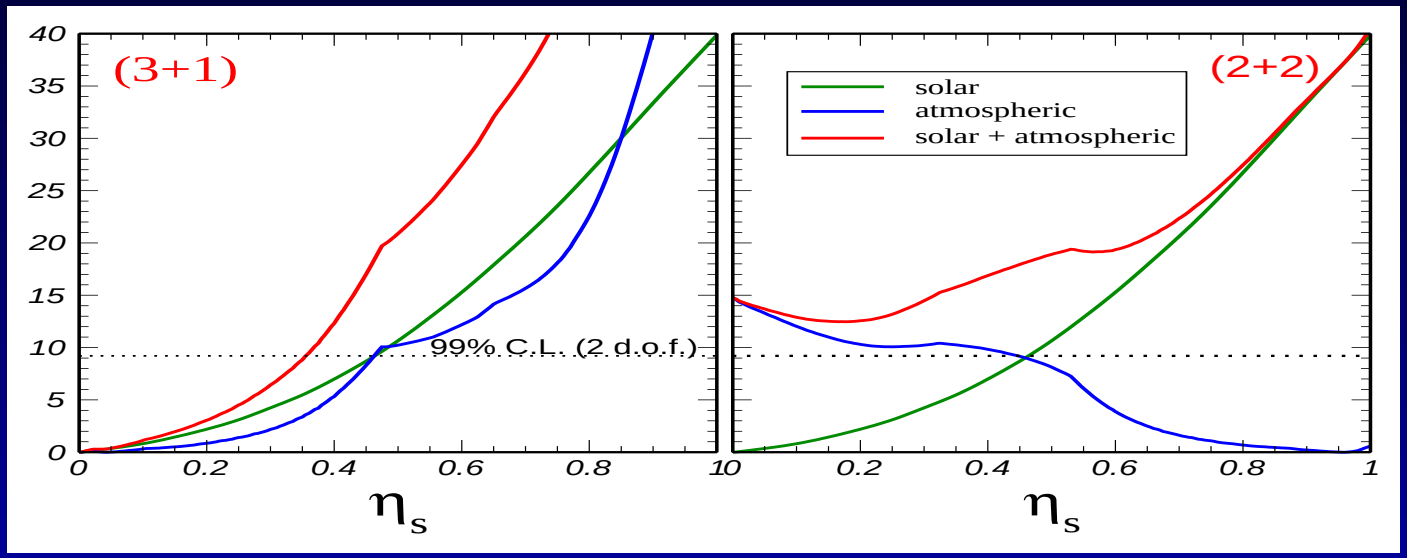
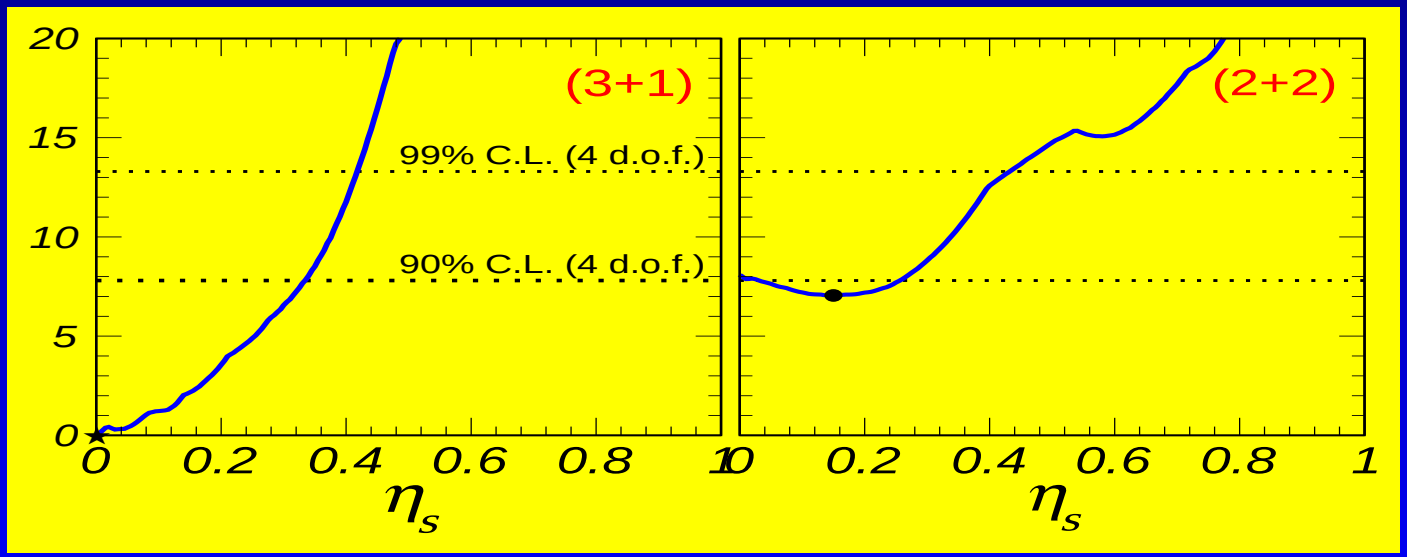
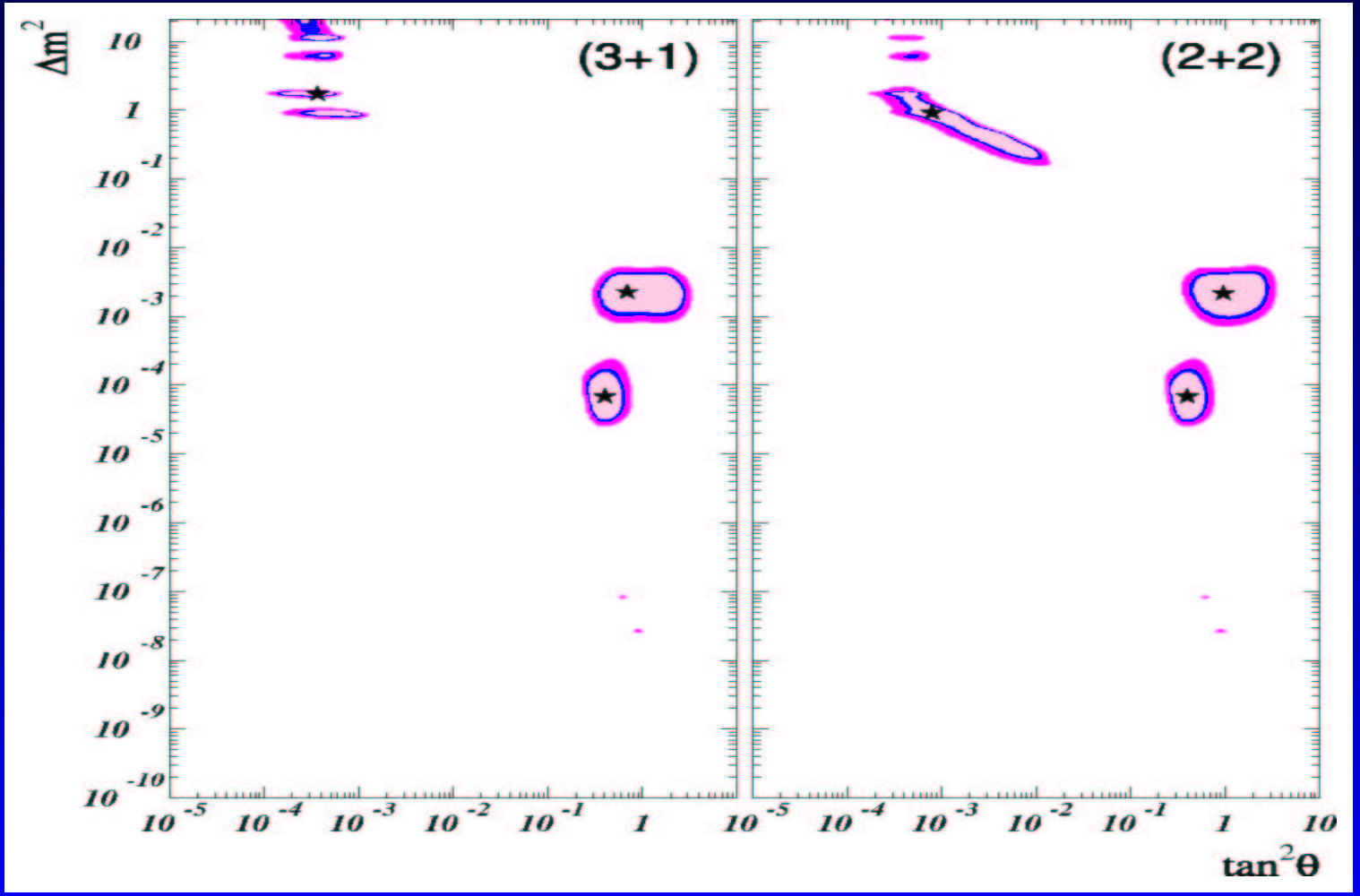




fitting all current oscillation data

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

Maltoni, Schwetz, Tórtola & JV 2002; upd of PRD65 (2002) 093004



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