FINAL TALK NOW-06

José W. F. Valle

AHEP Group, IFIC, Valencia

http://ahep.uv.es/

NOW06

27 plenary talks + 66 parallel session talks

- Session I: Probing low energy and mass scales

  Oliviero Cremonesi and Alessandro Melchiorri
- Session II: Neutrino Physics around MeV energies

  Kunio Inoue and Hisakazu Minakata
- Session III: Neutrino Physics at and above GeV energies

  Andrea Donini and Mauro Mezzetto
- Session IV: Exploring the range from TeV to ZeV

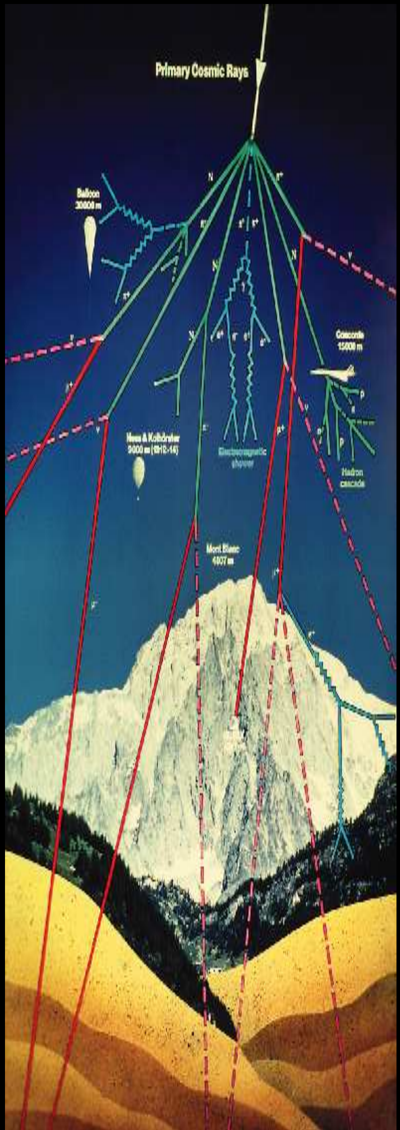
  Giuseppe Battistoni and Gennaro Miele
- Session V: Crossing different energy scales

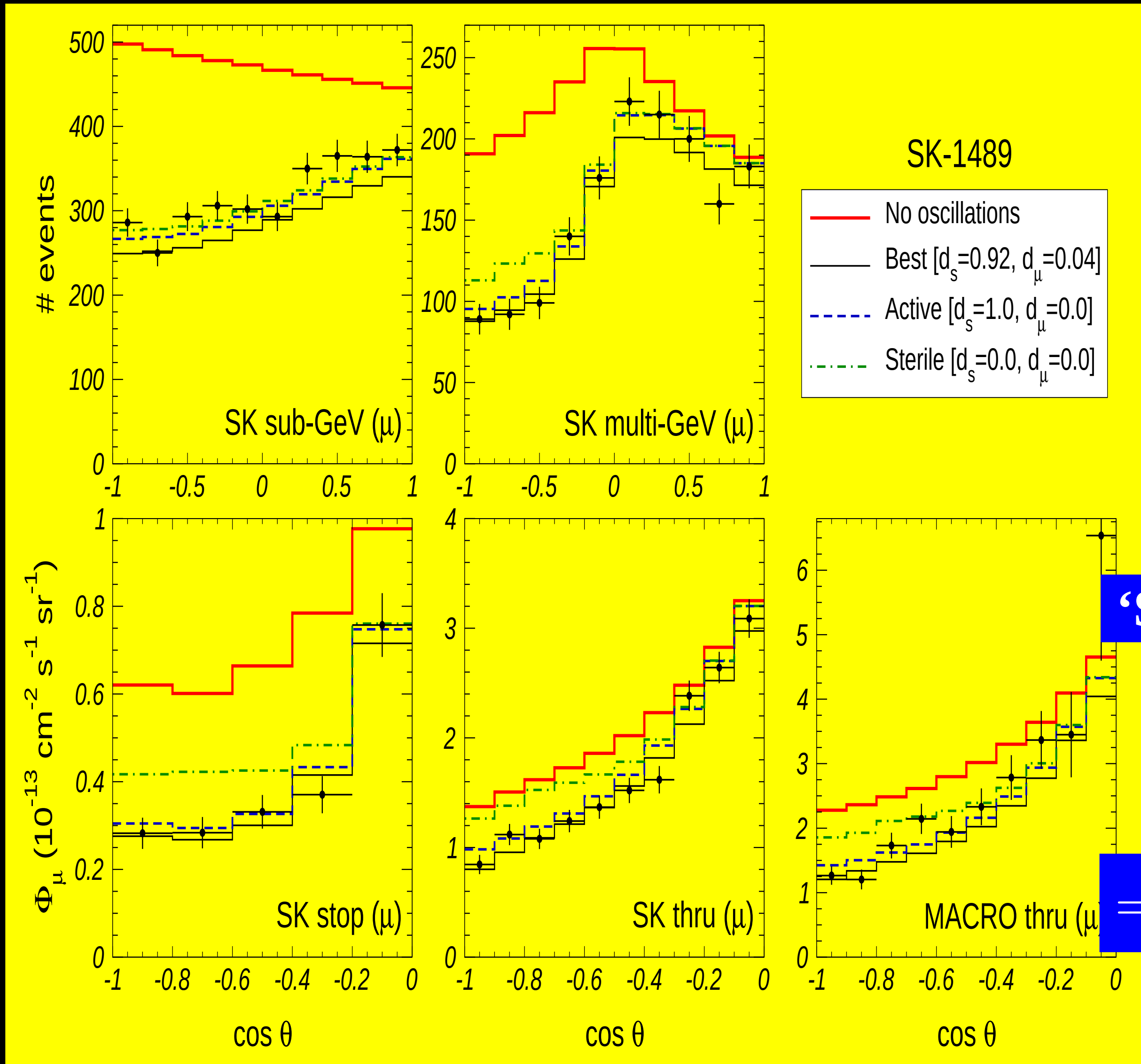
  Carlo Giunti and Donato Nicolò

ATMOSPHERIC SIGNAL

Maltoni et al, PRD67 (2003) 013011

deficit of earth-crossing ν_μ





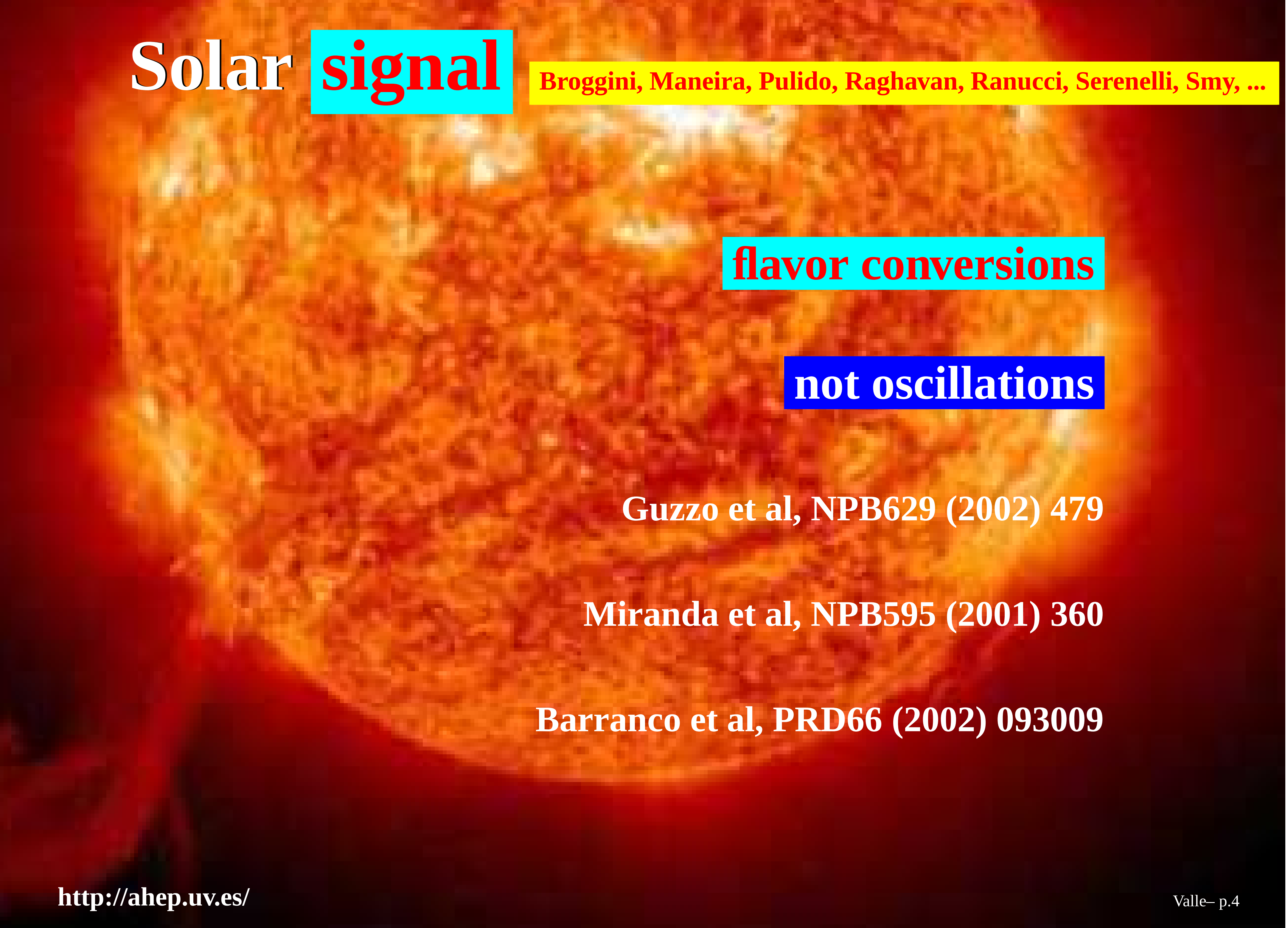
total sample

‘SELF-CONTAINED’

‘CONCLUSIVE’

⇒ flavor oscilllations

Bartol & Honda



Solar signal

Broggini, Maneira, Pulido, Raghavan, Ranucci, Serenelli, Smy, ...

flavor conversions

not oscillations

Guzzo et al, NPB629 (2002) 479

Miranda et al, NPB595 (2001) 360

Barranco et al, PRD66 (2002) 093009

BOTH CONFIRMED

- **accelerators** **K2K & MINOS confirm the atm ν_μ deficit and observe a distortion of the energy spectrum consistent with oscillations**

more is to come ... MINOS, CNGS/OPERA, T2K, NOVA, MINERVA, ..

talks by Gugliemi, Kajita, Kato, Kopp, Rebel, Sioli, ...

BOTH CONFIRMED

- **accelerators** **K2K & MINOS confirm the atm ν_μ deficit and observe a distortion of the energy spectrum consistent with oscillations**

  more is to come ... MINOS, CNGS/OPERA, T2K, NOVA, MINERVA, ..

  talks by Gugliemi, Kajita, Kato, Kopp, Rebel, Sioli, ...

- **reactors** **KamLAND also confirms solar ν_e deficit and sees spectrum distortion expected for oscillations + Chooz bound**

  more is to come ... D-Chooz, Daya-bay, RENO, Kaska, Angra, ...

  talk by Cabrera

LEPTON MIXING MATRIX

- $K = \omega_{23} \,.\, \omega_{13} \,.\, \omega_{12}$

Schechter-Valle'80

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

23=atm+acc

13=reactor + ..

12=solar+KL

LEPTON MIXING MATRIX

- $K = \omega_{23} \,.\, \omega_{13} \,.\, \omega_{12}$ Schechter-Valle'80

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

23=atm+acc 13=reactor + .. 12=solar+KL

- **oscillations depend only on Dirac phase** $n \geq 3$ *BHP80, Doi et al 81*

LEPTON MIXING MATRIX

- $K = \omega_{23} \,.\, \omega_{13} \,.\, \omega_{12}$ Schechter-Valle'80

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

23=atm+acc 13=reactor + .. 12=solar+KL

- **oscillations depend only on Dirac phase** $n \geq 3$ *BHP80, Doi et al 81*
- **the 2 new phases** $n \geq 2$ **appear in L-violating processes eg** $\beta\beta_{0\nu}$

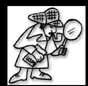
LEPTON MIXING MATRIX

- $K = \omega_{23} \cdot \omega_{13} \cdot \omega_{12}$

Schechter-Valle'80

$$
\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix}
\begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix}
\begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}
$$

23=atm+acc | 13=reactor + .. | 12=solar+KL

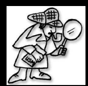
- **oscillations depend only on Dirac phase** $n \geq 3$ *BHP80, Doi et al 81*
- **the 2 new phases** $n \geq 2$ **appear in L-violating processes eg** $\beta\beta_{0\nu}$
- **in general K, not U** $\Rightarrow$ **NSI**  **see hep-ph/0608101**

LEPTON MIXING MATRIX

- $K = \omega_{23} \,.\, \omega_{13} \,.\, \omega_{12}$ Schechter-Valle'80

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & e^{i\phi_{23}} s_{23} \\ 0 & -e^{-i\phi_{23}} s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & e^{i\phi_{13}} s_{13} \\ 0 & 1 & 0 \\ -e^{-i\phi_{13}} s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & e^{i\phi_{12}} s_{12} & 0 \\ -e^{-i\phi_{12}} s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

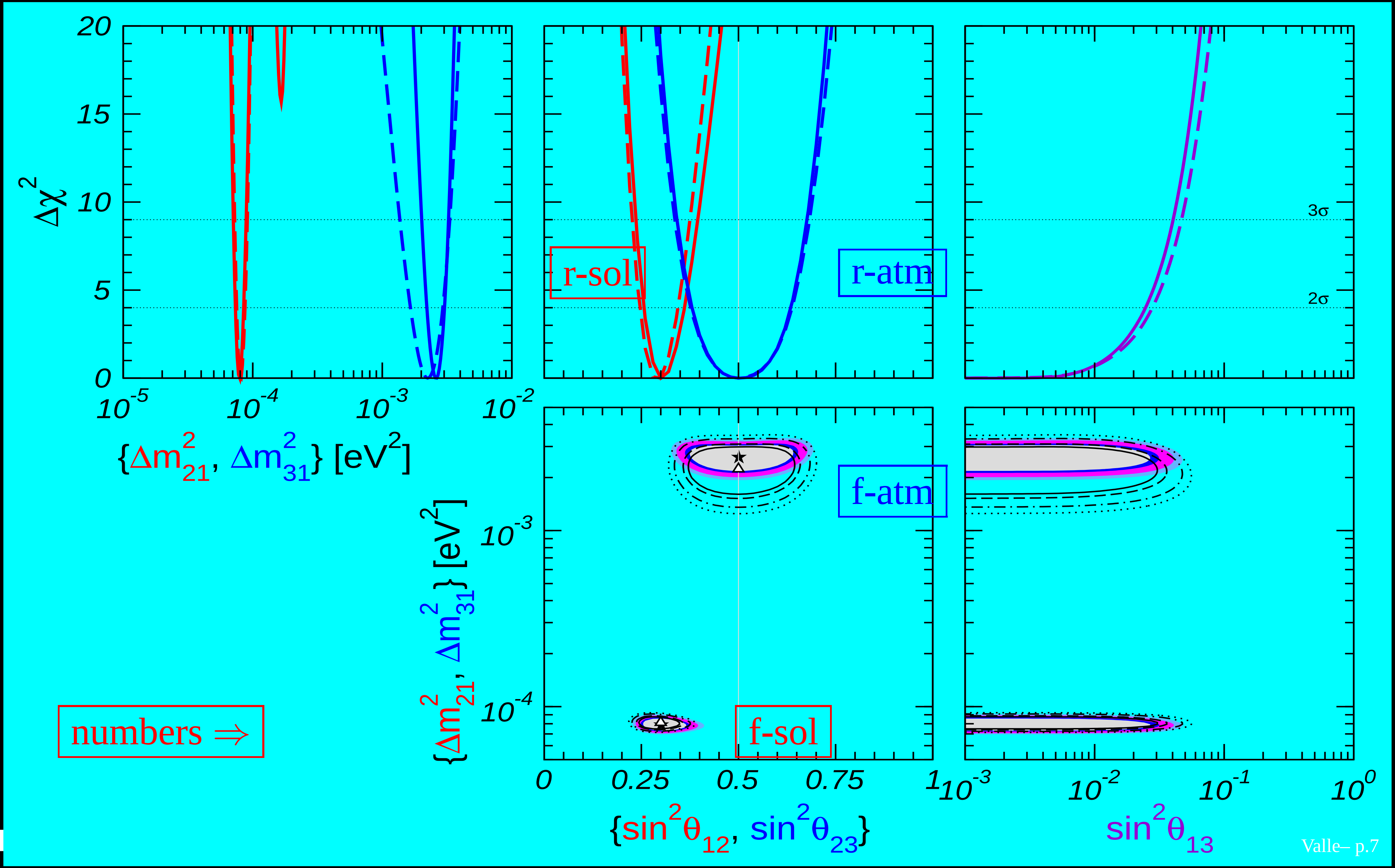
23=atm+acc 13=reactor + .. 12=solar+KL

- **oscillations depend only on Dirac phase** $n \geq 3$ *BHP80, Doi et al 81*
- **the 2 new phases** $n \geq 2$ **appear in L-violating processes eg** $\beta\beta_{0\nu}$
- **in general K, not U** $\Rightarrow$ **NSI**  **see hep-ph/0608101**
- **currently no expt is sensitive to CPV, so we also drop all** ϕ_{ij}

  5 oscillation parameters reasonable approximation

STATUS OF OSCILLATIONS-2006 Palazzo ...

M. Maltoni et al, NJP 6 (2004) 122 = hep-ph/0405172 v5 K2K, MINOS, SNO06, SSM06 t13 ⇒



ARE OSCILLATIONS ROBUST ?

Do we understand

... the Sun?

... neutrino propagation ?

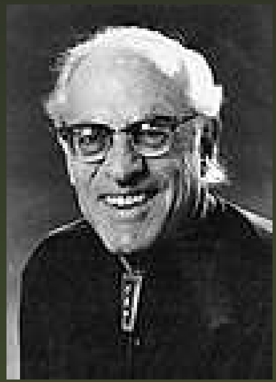
... neutrino interactions ?

ROLE OF REACTORS Shirai (geo)..

neutrino discovered in reactor ..

KamLAND has solved SNP

identifying oscillation as “the” soln

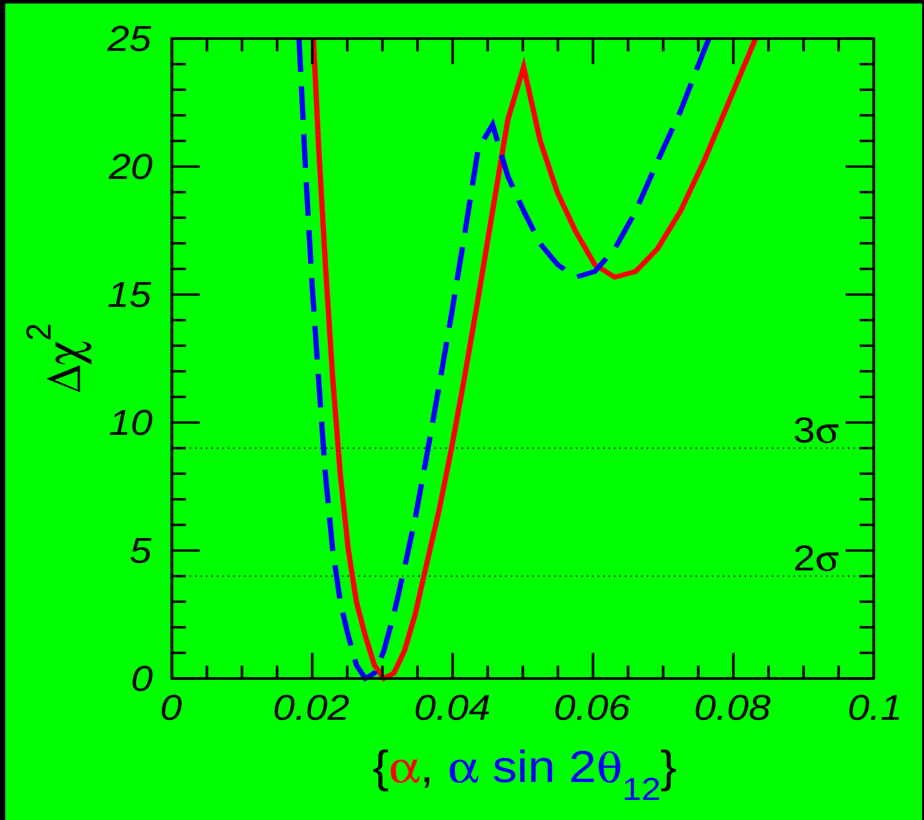


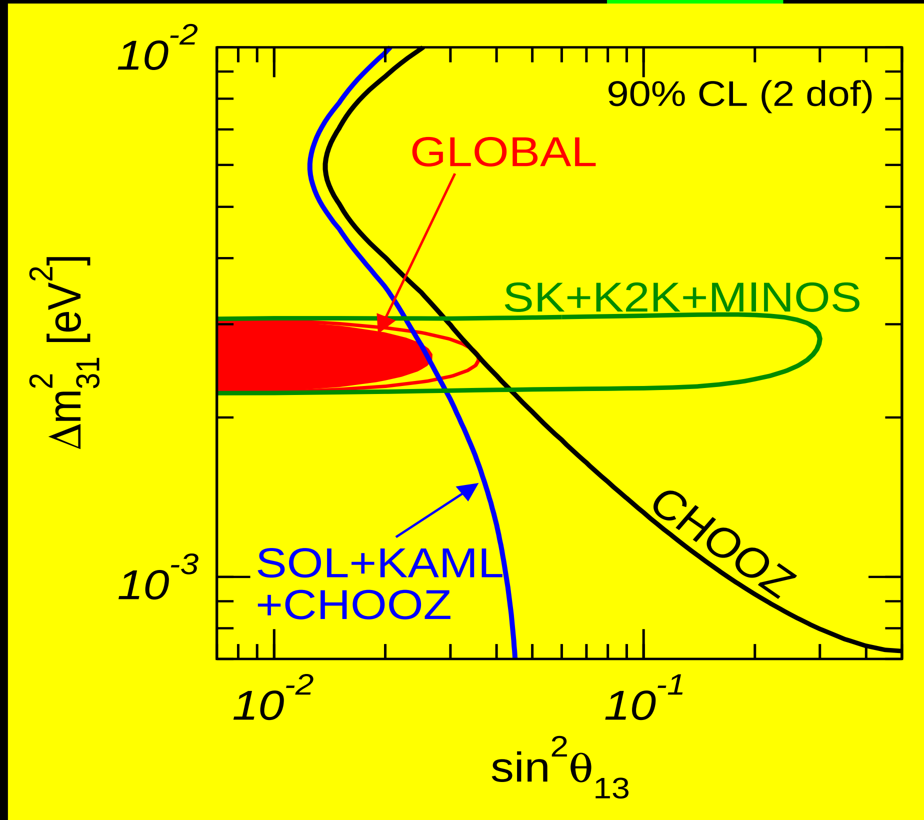
- noisy Sun robust — Burgess et al JCAP0401 (2004) 007
- SFP robust — Miranda et al PRL93 (2004) 051304 & PRD70 (2004) 113002
- NSI not quite robust yet — Miranda etal hep-ph/0406280

STATUS OF SMALL PARAMETERS

M. Maltoni et al, NJP 6 (2004) 122 = **hep-ph/0405172** **version 5** **2006-updated**

$\frac{\Delta m^2_{\rm SOL}}{\Delta m^2_{\rm ATM}}$ and θ_{13}



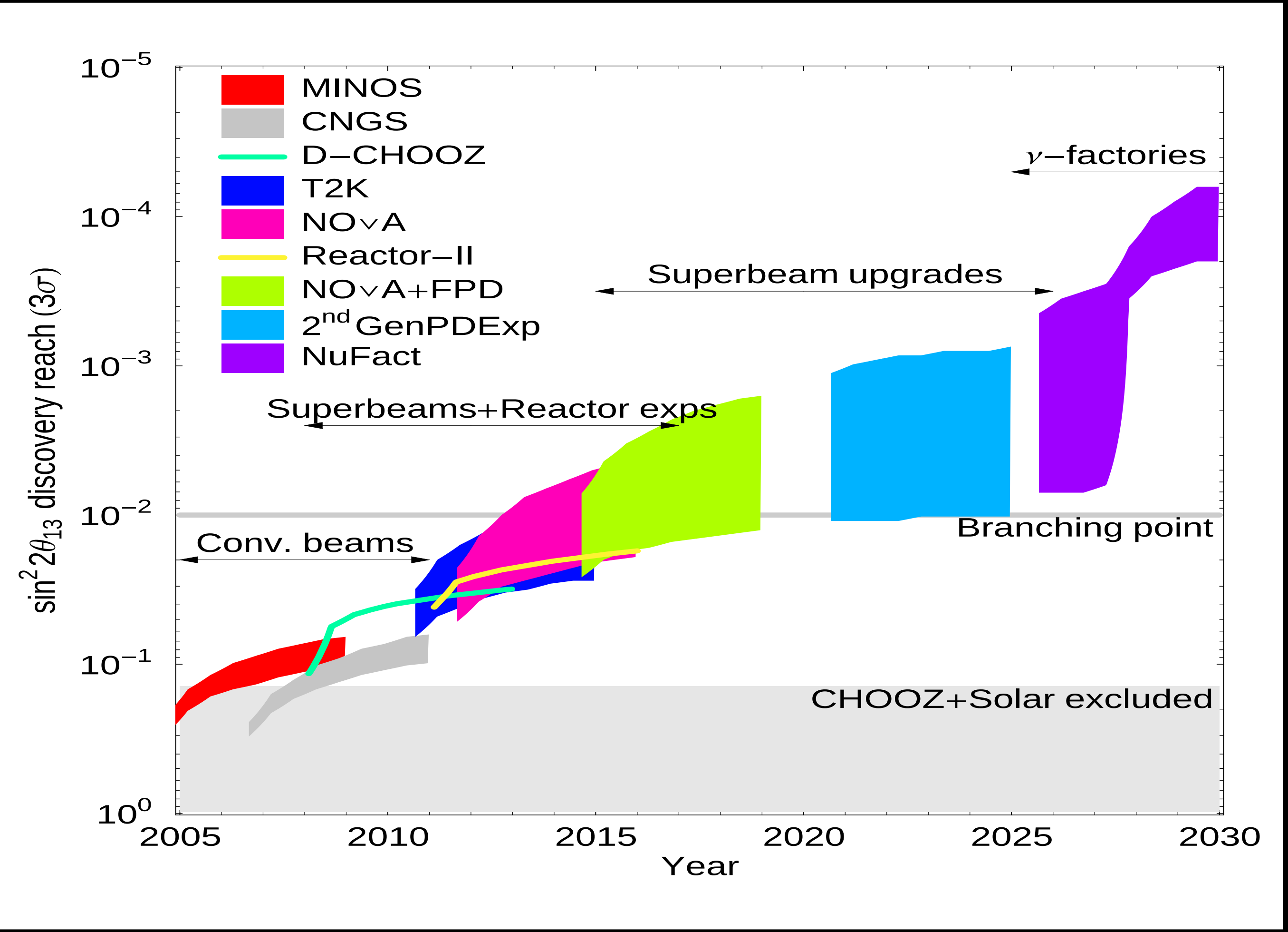


solar+KamLAND improve upon Chooz **double price for CPV**

challenge for upcoming LBL reactor/accel expts

Hunt for θ_{13} Declais, Huber, Kajita, Kato, Kopp, Lindner, Nunokawa, Schwetz, ...

- LBL programme at reactors & accelerators



Albrow, et al

Huber, Lindner, Winter, et. al.

if no NSI ⇒

see

PRL88 (2002) 101804

PRD66, 013006 (2002)

Katsanevas **LS**: LENA, **LAr**: GLACIER, **WC**: MEMPHYS, UNO, HK ...

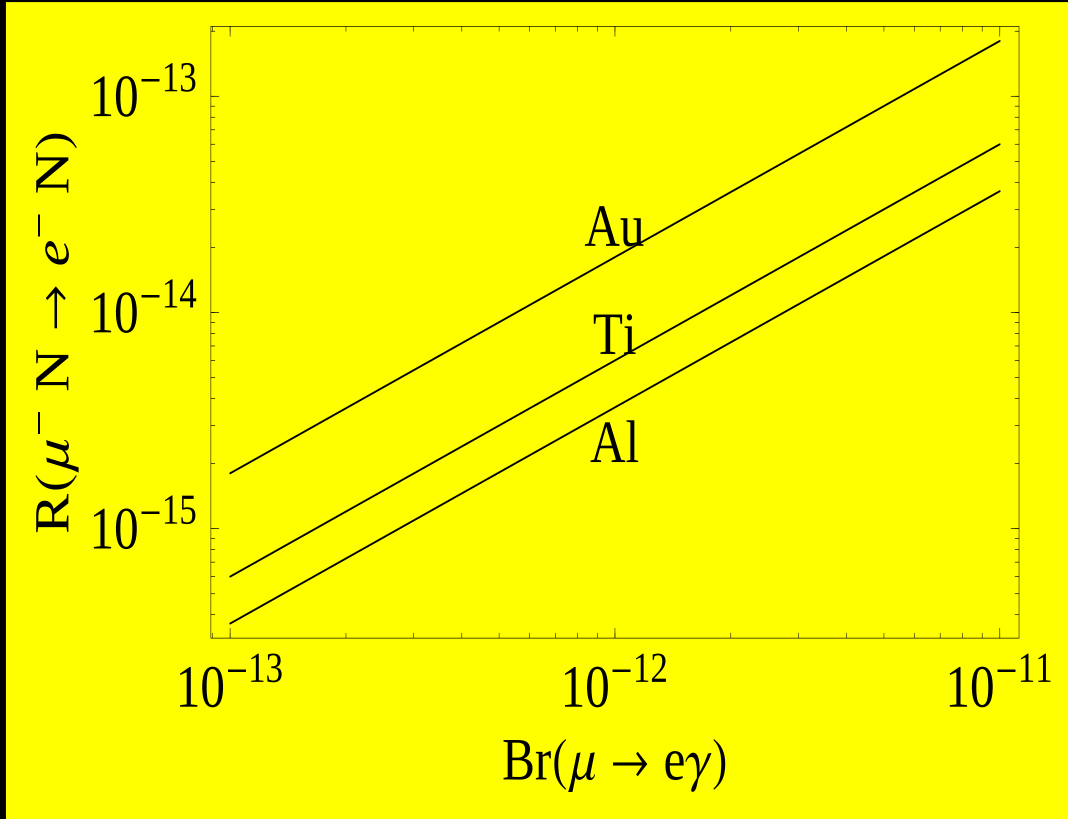
other ways? D/N solar-nu studies ⇒ Akhmedov et al JHEP05 (2004) 057

LFV BEYOND OSCILLATIONS

Baldini, Kuno, Masiero,...

LFV & CPV can exist as $m_\nu \to 0$

$M = 1$ TeV, best-fit oscil param



from Deppisch & JV, PRD72 (2005) 036001
Deppisch, Kosmas & JV NPB752 (2006) 80

hope for MEG 10^{-13} & PRISM 10^{-18}

NHL

Bernabeu et al, Branco, Rebelo and JV,
Rius & JV, Gonzalez-Garcia & JV
Ilakovac & Pilaftsis...

SUSY

Hall, Kostelecky & Raby
Borzumati & Masiero
Barbieri & Hall, Casas & Ibarra;
Antusch, Arganda, Herrero, Teixeira, ...

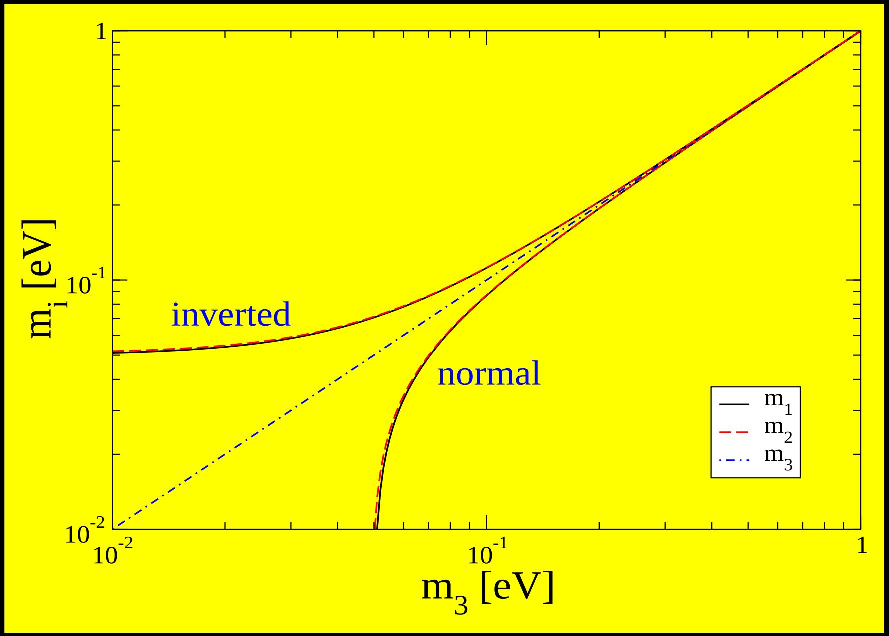
LFV without nu-mass $\Rightarrow$

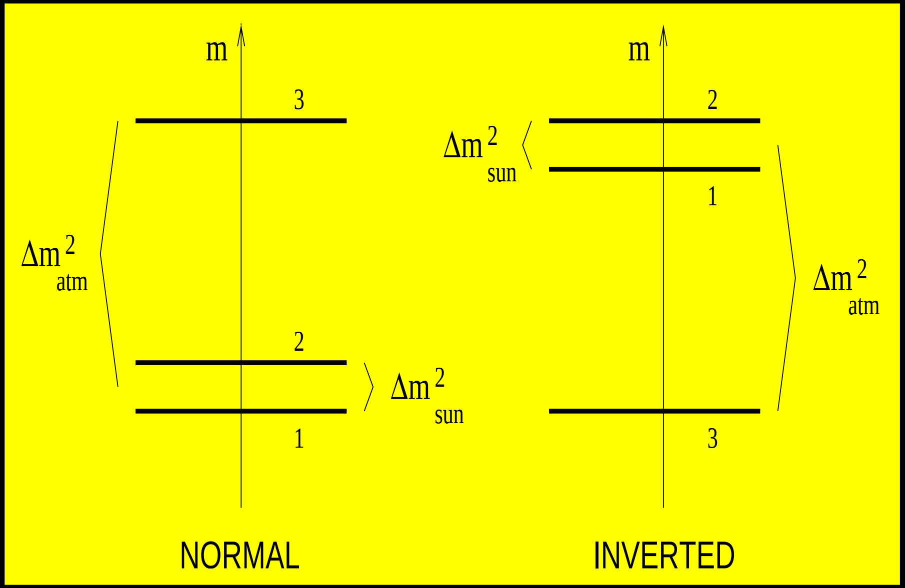
WHICH SPECTRUM?

oscil do not probe absolute masses

can not choose spectrum

need for kinematical tests !





BETA DECAY **Sisti, Weinheimer, ...**

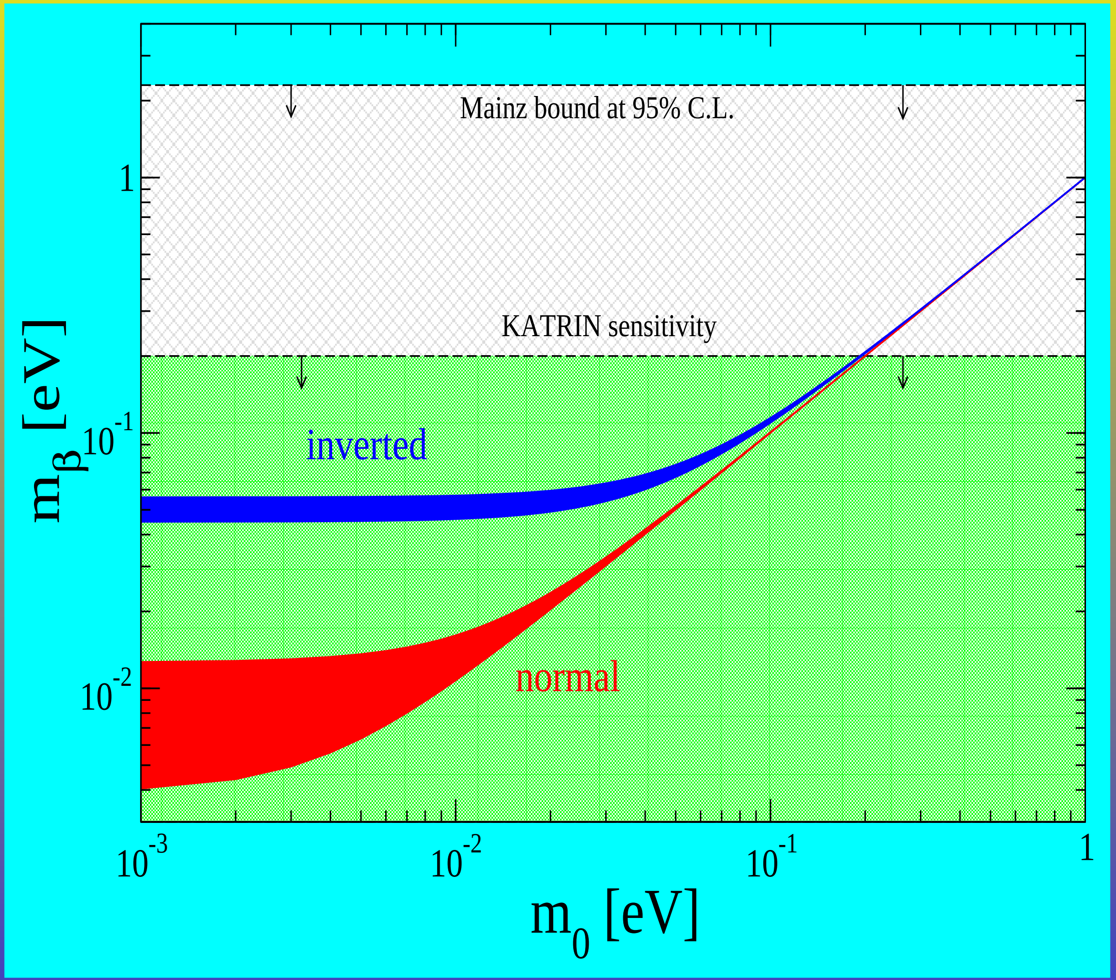
test

absolute nu-mass scale

Katrin will be next high precision neutrino mass experiment

scaling up size & source intensity

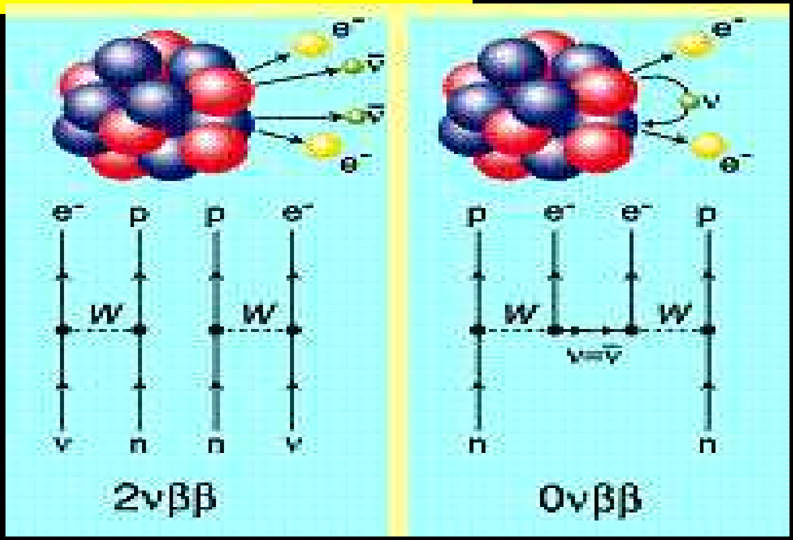
great challenge !!



Masood et al 2006 **courtesy ot Tortola**

0-nu DBD-1

Avignone, Bettini, Fiorini, Pavan, Simkovik, Vala, Vogel, ...



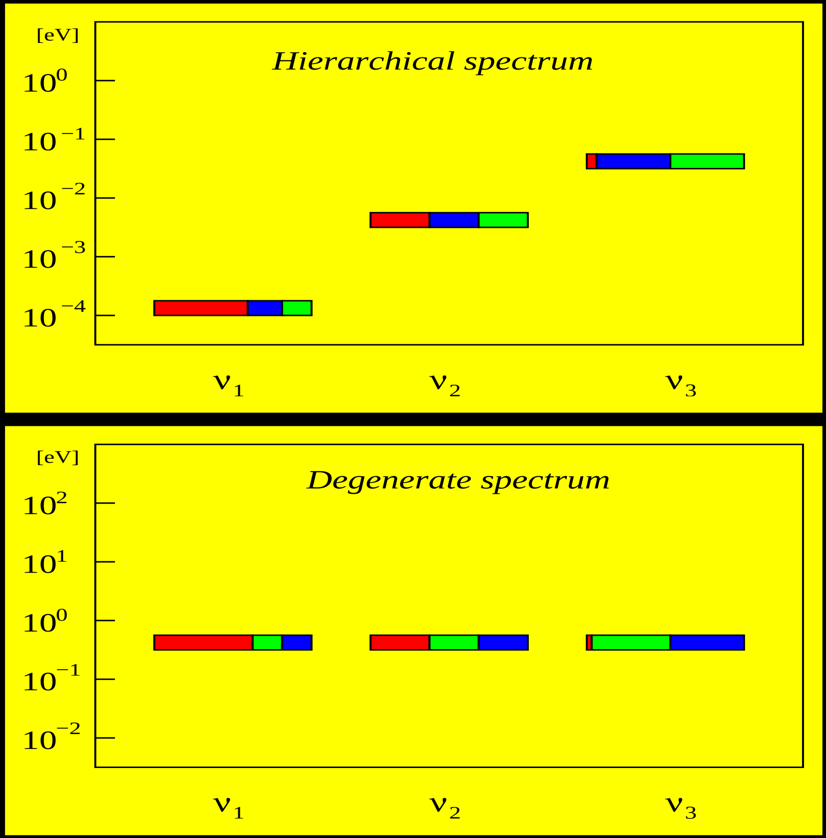
- **should occur with amplitude propto**

$$m_{\beta\beta} = \sum_j K_{ej}^2 m_j$$

- **3 masses:** m_i
- **2 angles:** θ_{12} **and** θ_{13}
- **2 CP phases:** ϕ_{12}, ϕ_{13}

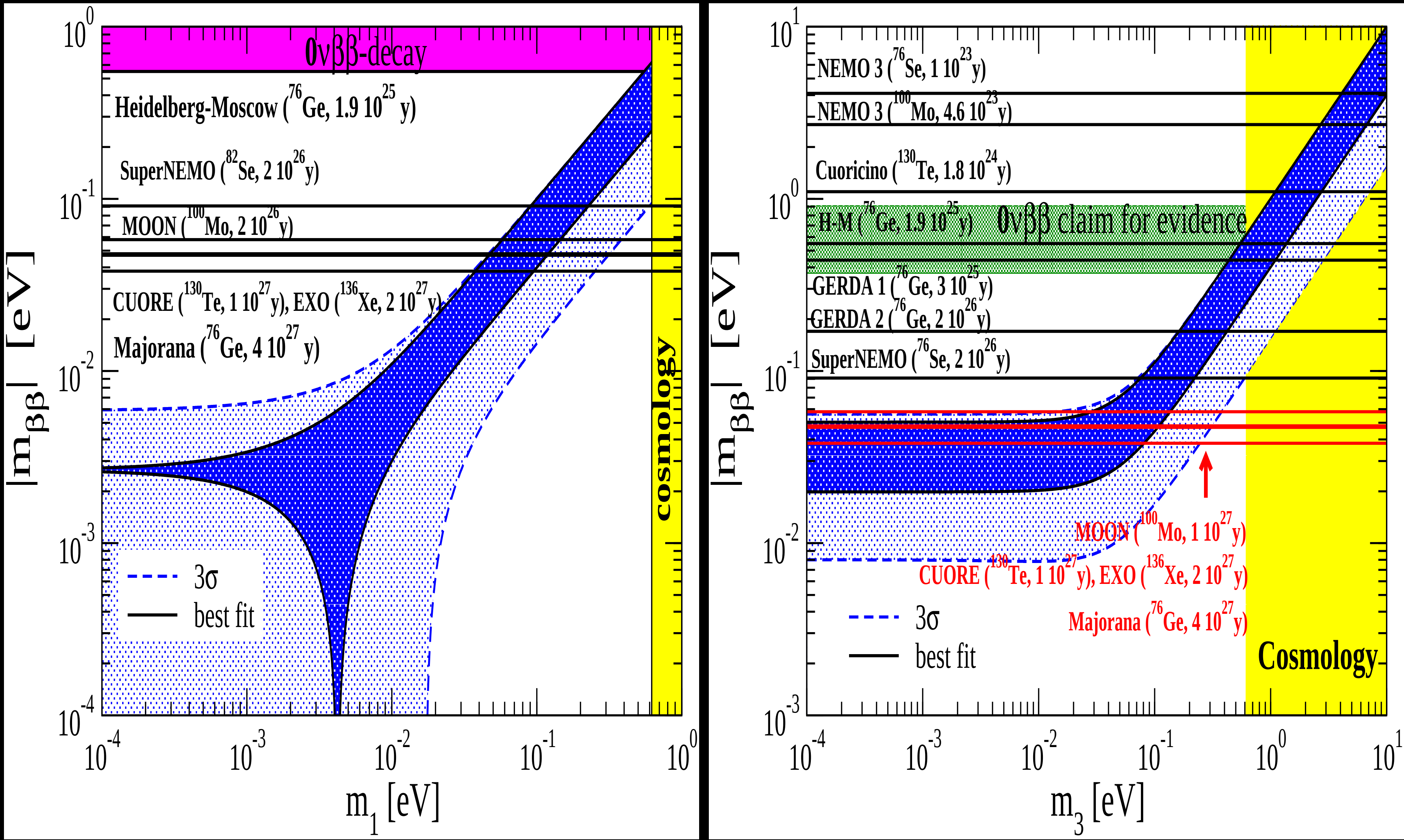
in addition to abs m-nu scale

sensitivity to Majorana phase



0-nu DBD-2

Avignone, Bettini, Fiorini, Pavan, Simkovik, Vala, Vogel, ...



Rodin, Faessler, Simkovic, Vogel NPA 766 (2006) 107

http://ahep.uv.es/

courtesy of Simkovic

Hirsch's talk at Nu-2006

LOWER BOUND FOR 0-nu DBD?

A_4 **triplet model of nu-masses**

Hirsch, et al, PRD72 (2005) 091301

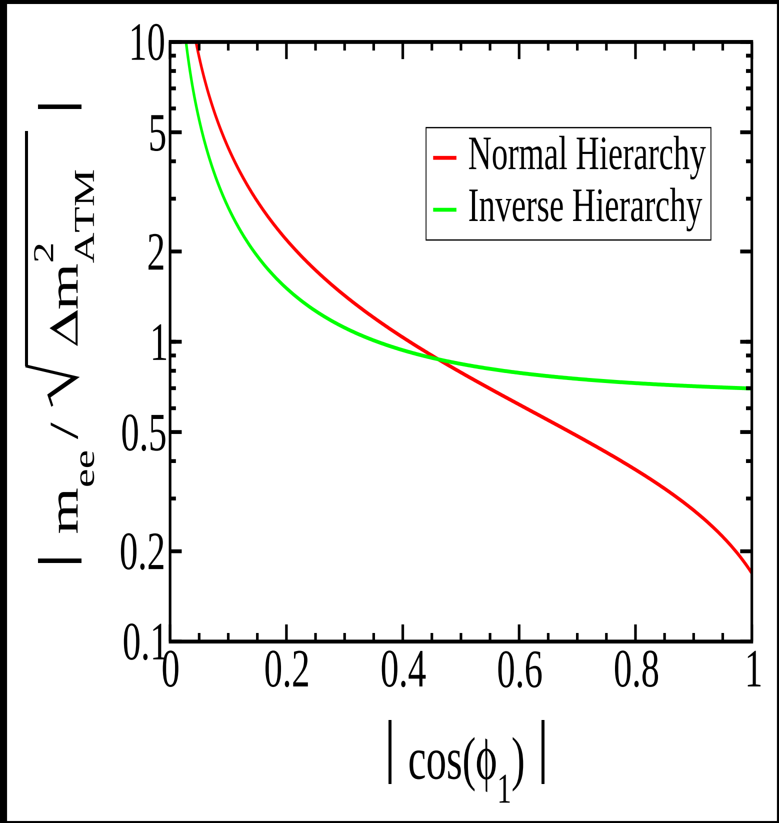
$$M_\nu = \begin{bmatrix} a+2b & d & d \\ d & a-b & d \\ d & d & a-b \end{bmatrix}$$

$\theta_{23} = \pi/4$ $\tan^2\theta_{12} = 1/2$ $\tan^2\theta_{13} = 0$

$|\langle m_{\beta\beta}\rangle| \geq 0{,}17\sqrt{\Delta m^2_{\rm ATM}}$

even for normal hierarchy $\longrightarrow$

sensitive to Majorana phase



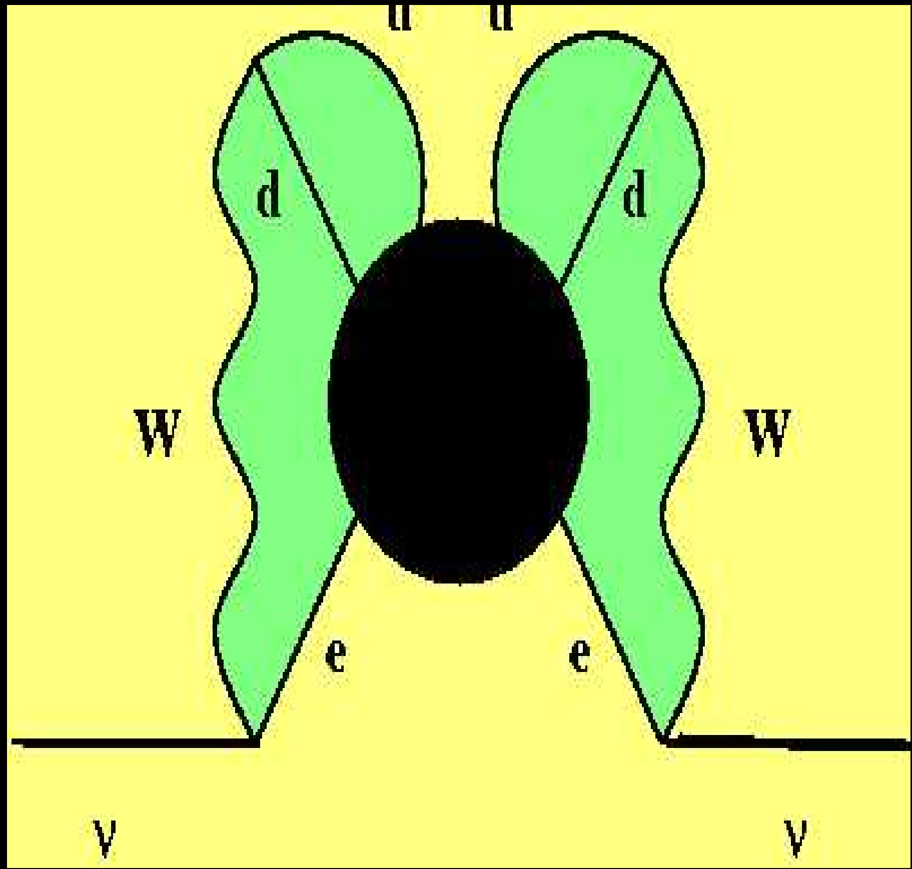
SIGNIFICANCE of 0-nu DOUBLE BETA DECAY

in a weak interaction gauge theory non-zero $\beta\beta_{0\nu}$ implies at least one neutrino is Majorana

tests majorana nature

IRRESPECTIVE OF MECHANISM

no such theorem for flavor violation



Schechter and JV, PRD25 (1982) 2951

NEUTRINOS AS PROBES

neutrinos ideal to monitor the interior of the sun, stars and the HE Universe

- geo-probes ⇒
- astro-probes
  - Sun ⇒
  - SN neutrinos
  - HE neutrinos
- neutrinos as Big Bang probes

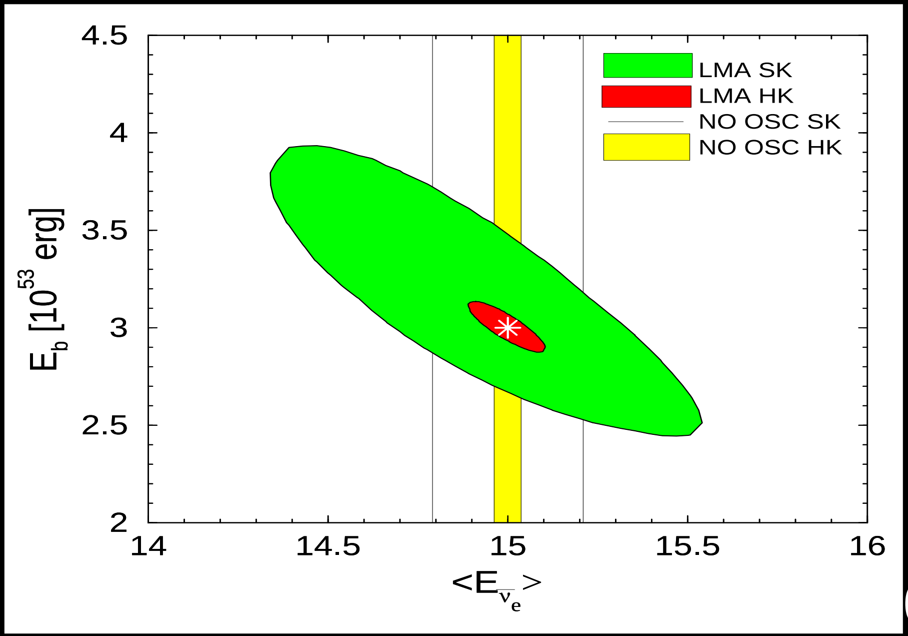
Neutrinos as SN-probe

Cardall, Fleurot, Lunardini, Vagins...

Minakata et al, PLB542 (2002) 239

SN parameters from precise nu-properties

simulate nu-signal from 10 kpc galactic SN



(small θ_{13} approx)

improved SN-parameter determination

new effects in nu-conversions at SN-core (neutron-rich regime)

Valle PLB199 (1987) 432, Nunokawa et al 96, Hannestad et al 06, Esteban et al, 06

HIGH ENERGY NEUTRINOS **Billoir, Karle, Flaminio,..**

- **expect nu's with higher energies, eg AGN, GRB ..**

HIGH ENERGY NEUTRINOS **Billoir, Karle, Flaminio,..**

- expect nu's with higher energies, eg AGN, GRB ..
- accelerated primaries make pions $\Rightarrow \Phi_\gamma \sim \Phi_\nu$ due to isospin

HIGH ENERGY NEUTRINOS

Billoir, Karle, Flaminio,..

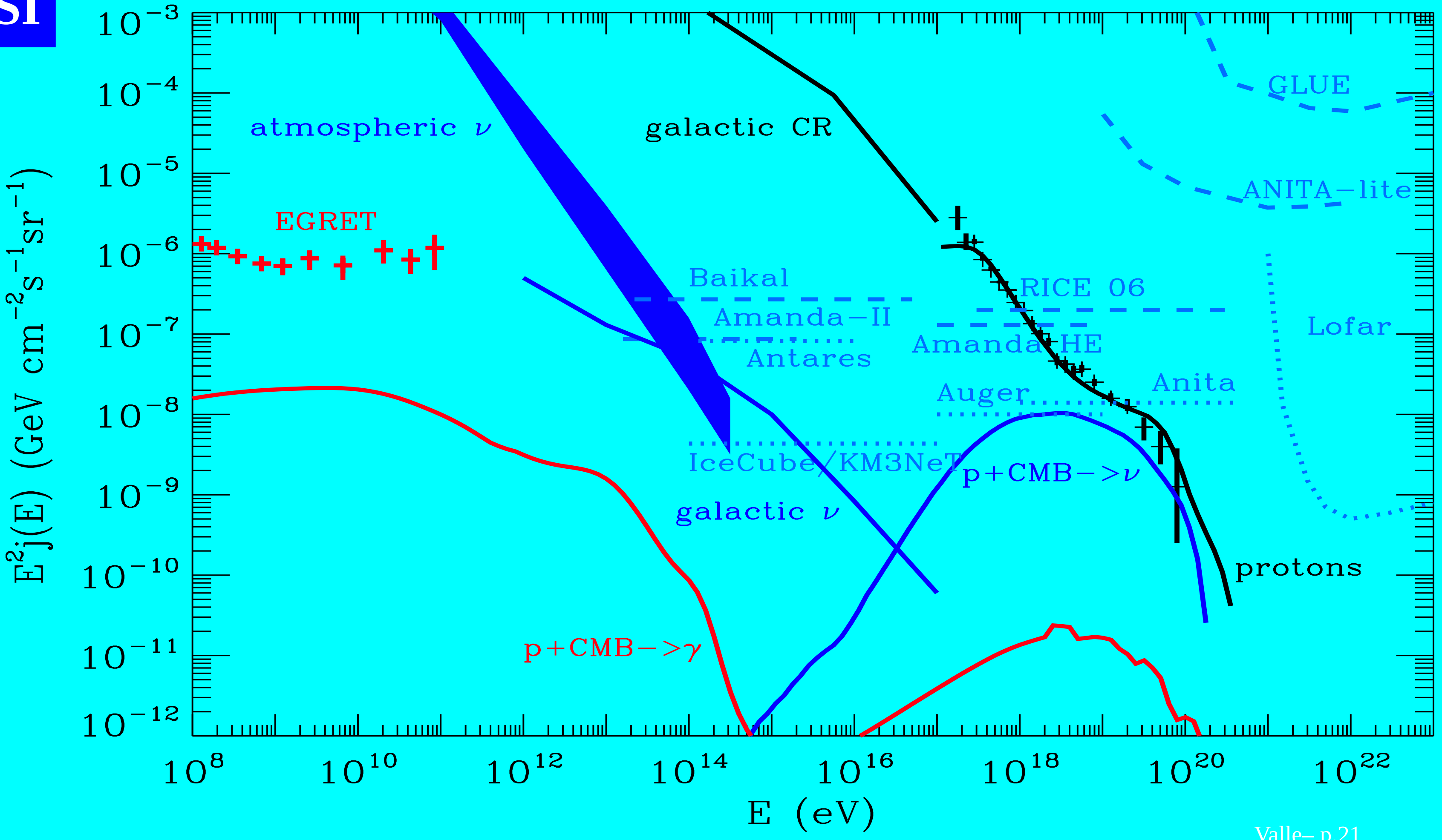
- expect nu’s with higher energies, eg AGN, GRB ..
- accelerated primaries make pions $\Rightarrow \Phi_\gamma \sim \Phi_\nu$ due to isospin
- nu-spectrum unmodified sources & nu-properties

flavor ratios, NSI

synergy $\Rightarrow$

Sigl $\Rightarrow$

Stanev



http://ahep.uv.es/

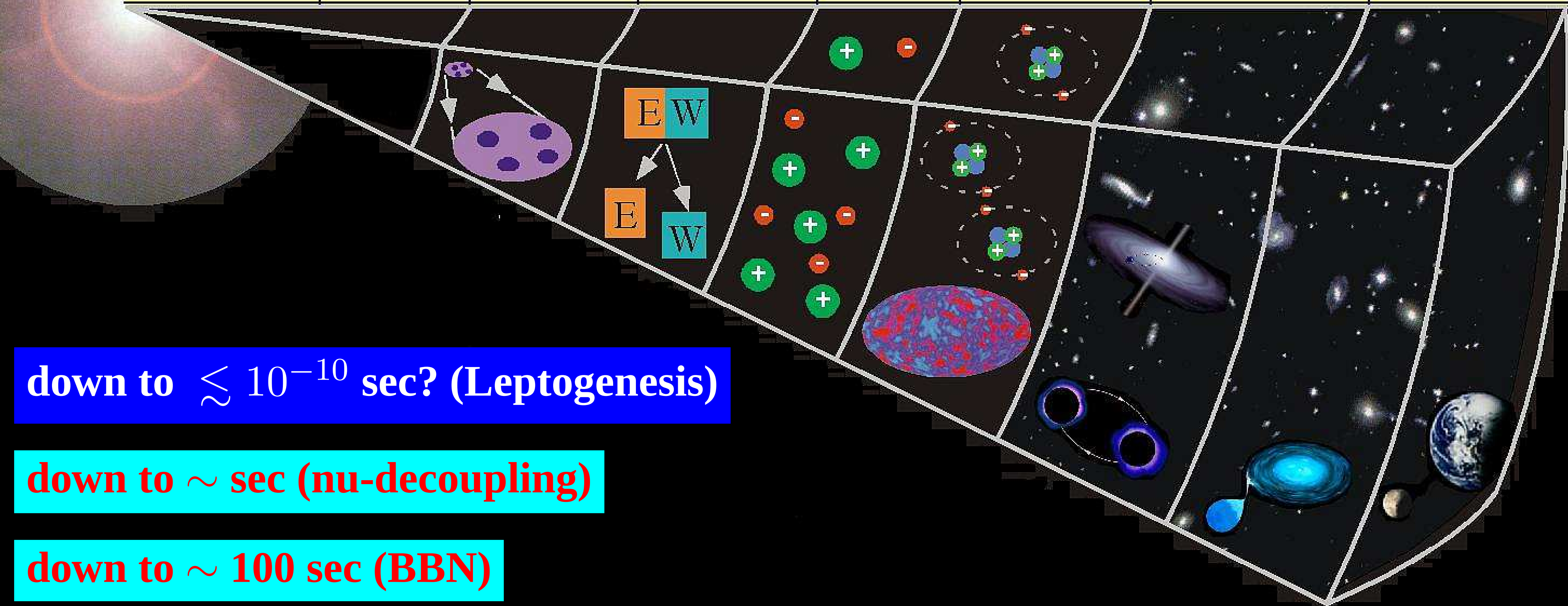
Big Bang

neutrinos as Big Bang probes

time

neutrinos probe deeper

10^{-44} s	10^{-35} s	10^{-32} s	10^{-10} s	300 s	3×10^{5} yr	1×10^{9} yr	15×10^{9} yr
Superstring (?) Era	GUT Era	Inflation Era	Electro-weak Era	Particle Era	Recombination Era	Galaxy and Star Formation	Present Era



down to $\lesssim 10^{-10}$ sec? (Leptogenesis)

down to $\sim$ sec (nu-decoupling)

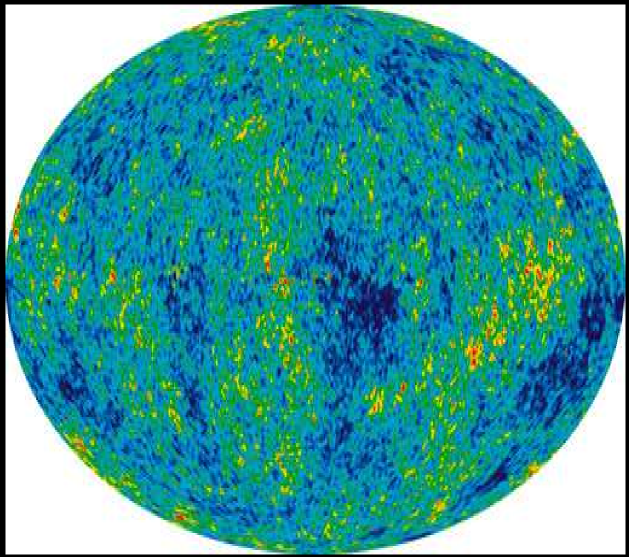
down to $\sim$ 100 sec (BBN)

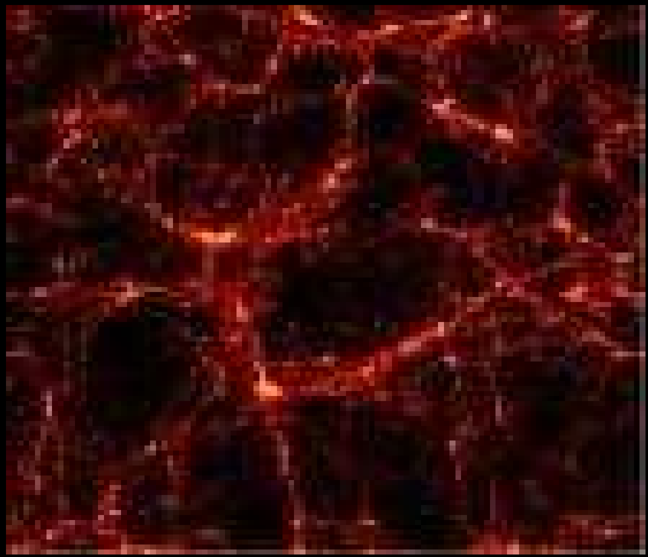
CMB & LSS .

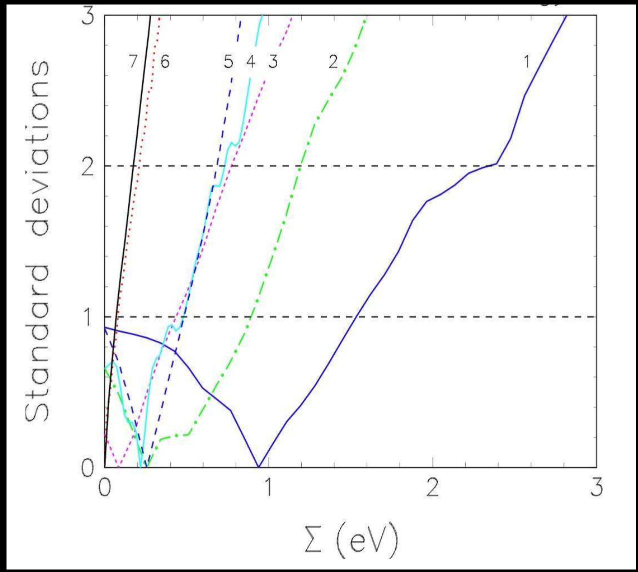
Elgaroy, Mangano, Pastor, Villante, Viel, ..

CMB and LSS

Elgaroy, Palazzo, Pastor, Viel, ..



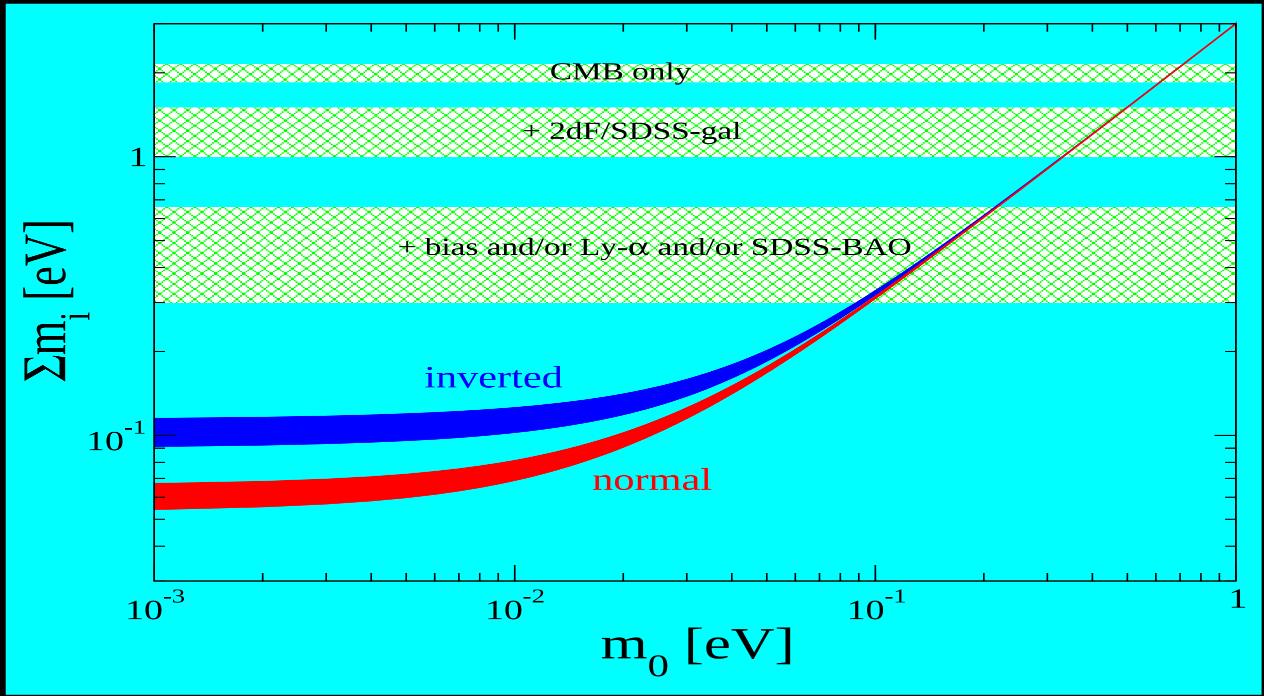




Fogli et al

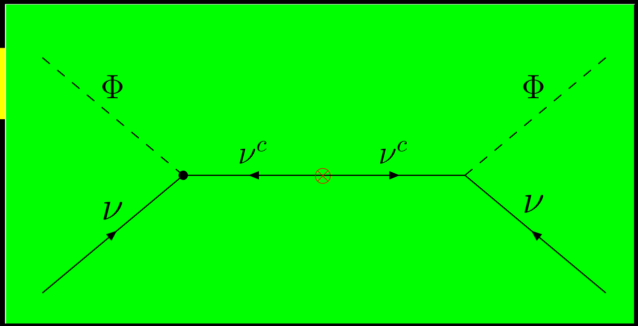
Hannestad

Lesgourgues & Pastor ⇒



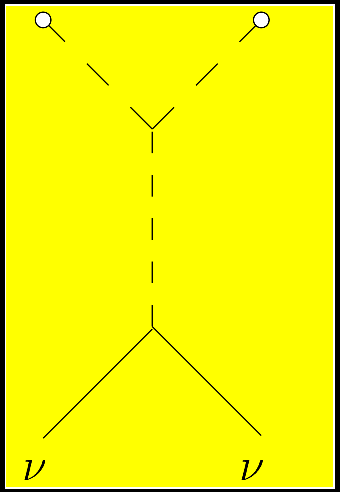
http://ahep.uv.es/

Seesaw & leptogenesis **Akhmedov, di Bari, Ma, Petcov**



why nu-masses small?

- $SU(2) \otimes U(1)$ singlet exchange: type I
- heavy 3-plet scalar boson exchange: type II



many realizations

$$\begin{pmatrix} M_L & D \\ D^T & M_R \end{pmatrix}$$

$$M_{\nu\ \text{eff}} = M_L - D M_R^{-1} D^T$$

where D is the $SU(2) \otimes U(1)$ breaking Dirac mass

both suppressed by new scale

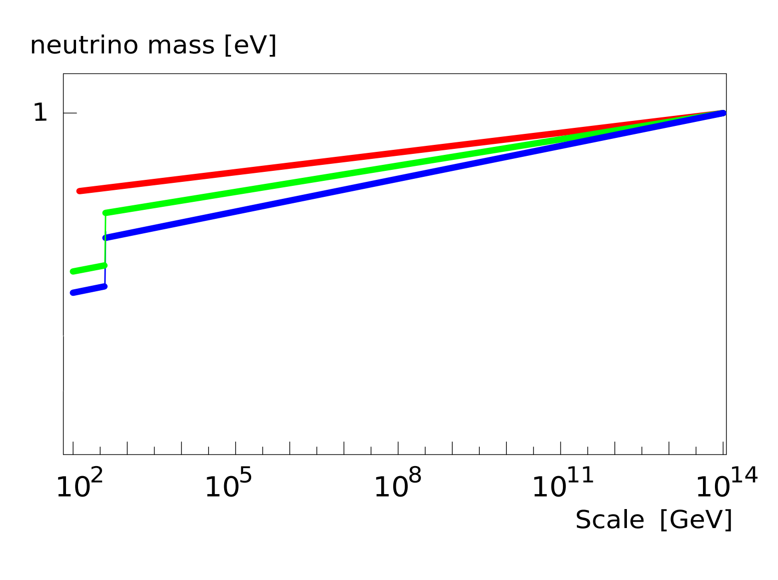
more to seesaw than meets the eye... seesaw KS $\Rightarrow$ **hep-ph/0608101**

Buchmuller, Peccei, Yanagida ; Farzan & JV PRL (2006) 011601; Hirsch et al hep-ph/0608006

PREDICTING NU-MASSES & MIXINGS

neutrino unifi cation "top-down"

Chankowski et al PRL86 (2001) 3488



due to A4 Babu, Ma & JV, PLB552 (2003) 207
Hirsch et al, PRD69 (2004) 093006

$\theta_{23} = \pi/4$ $\theta_{13} = 0$ $\theta_{12} = \mathcal{O}(1)$

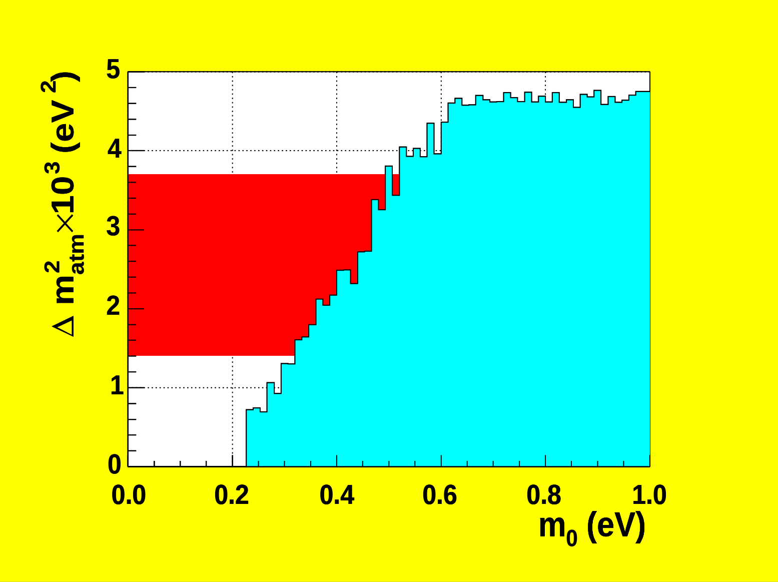
[when $\theta_{13} \neq 0$ CPV is maximal]

minimal nu-mass $m \gtrsim 0.3$ eV

Grimus, Lavoura; Kitabayashi, Yasue; Ma et al; Altarelli, Feruglio

$B(\mu \to e\gamma) \gtrsim 10^{-15}, B(\tau \to \mu\gamma) \gtrsim 10^{-9}$

light slepton



PREDICTING NU-ANGLES-2 **Feruglio, He, ..**

tri-bimaximal mixing at high energies

Harrison, Perkins & Scott

$$U_{\mathrm{HPS}} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$ gives

$\tan^2\theta_{\mathrm{ATM}} = \tan^2\theta_{23}^0 = 1$ $\sin^2\theta_{\mathrm{Chooz}} = \sin^2\theta_{13}^0 = 0$ $\tan^2\theta_{\mathrm{SOL}} = \tan^2\theta_{12}^0 = \frac{1}{2}$

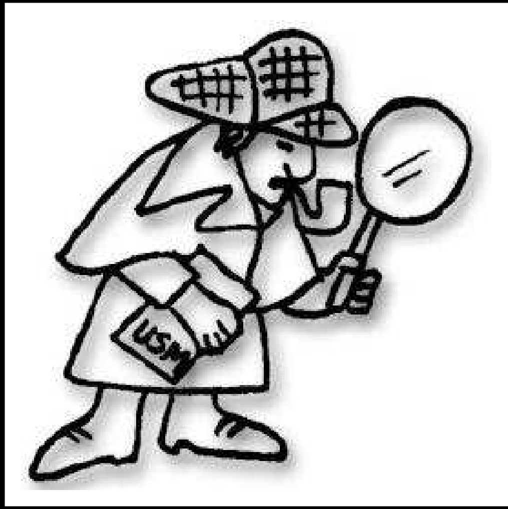
mainly θ_{SOL} modified at low energies by radiative corrections

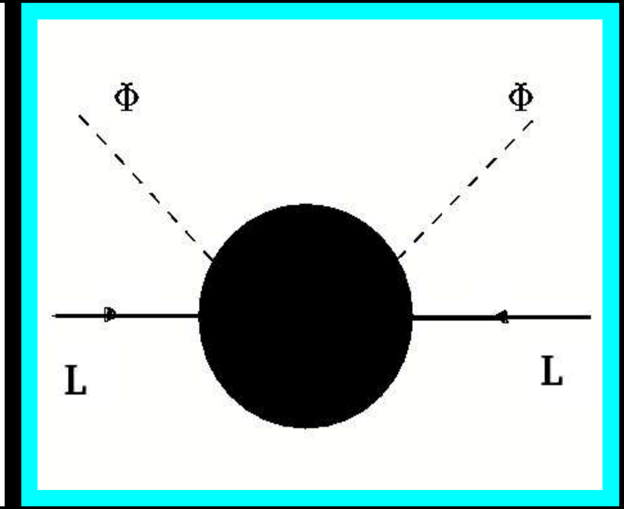
Hirsch, et al hep-ph/0606082 (mSUGRA)

related work by

also Altarelli & Feruglio 06, He & Zee 06, Z Z Xing, ...

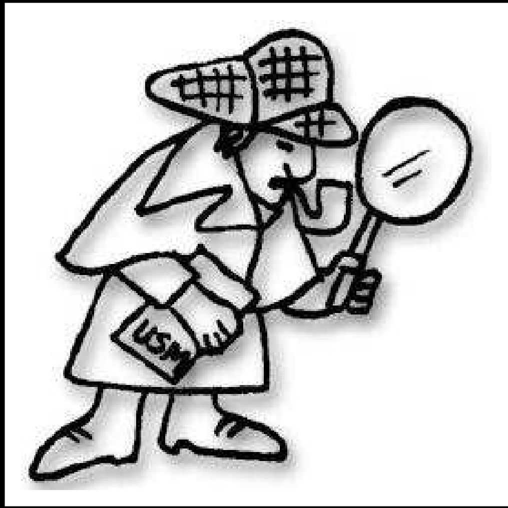
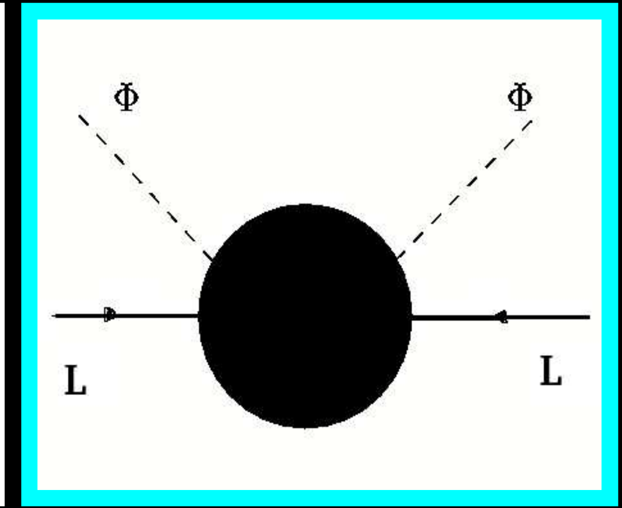
MYSTERY REMAINS





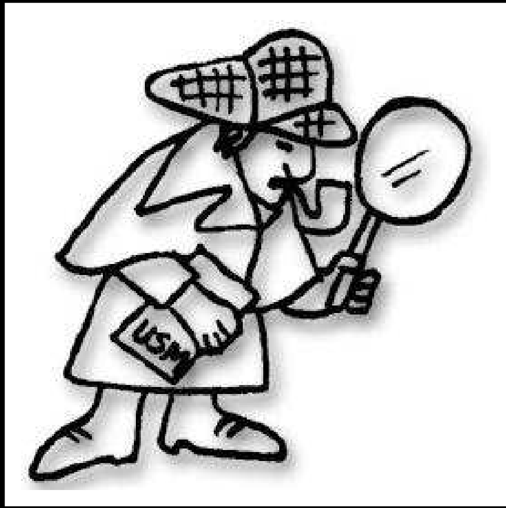
Weinberg PRD22 (1980) 1694

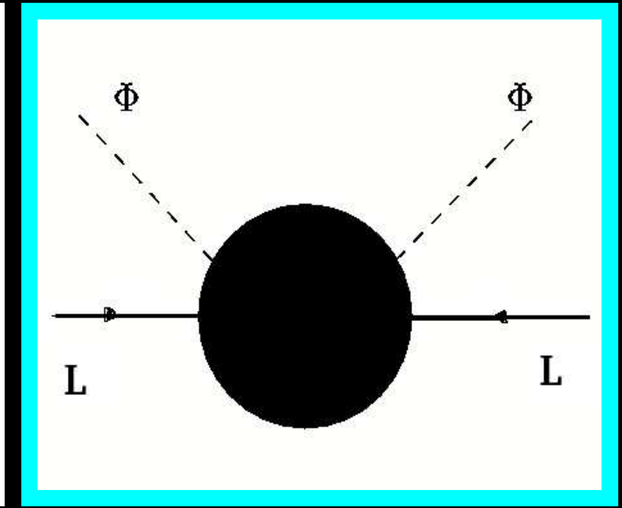
MYSTERY REMAINS

-  

Weinberg PRD22 (1980) 1694
- which scale ⇒

MYSTERY REMAINS

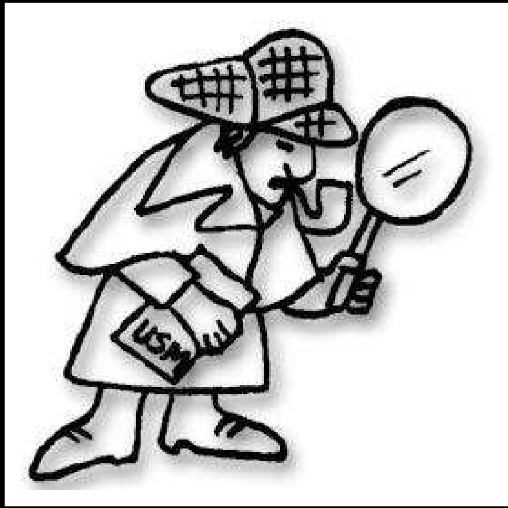


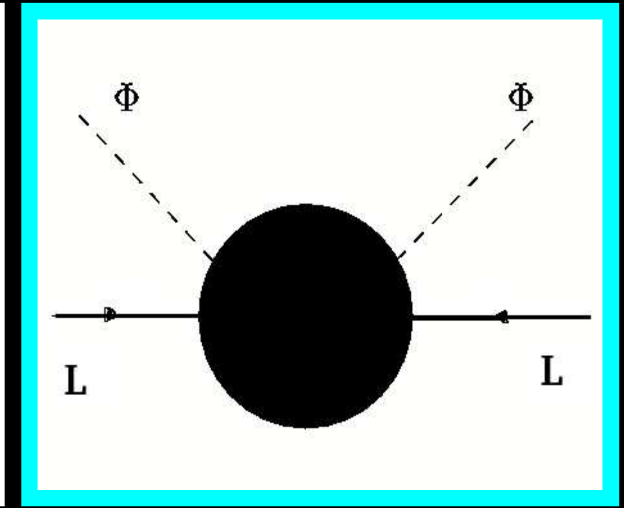


Weinberg PRD22 (1980) 1694

- which scale ⇒
- which flavour structure

MYSTERY REMAINS

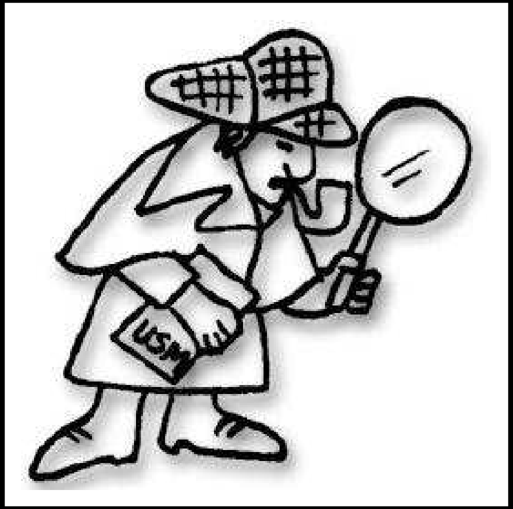


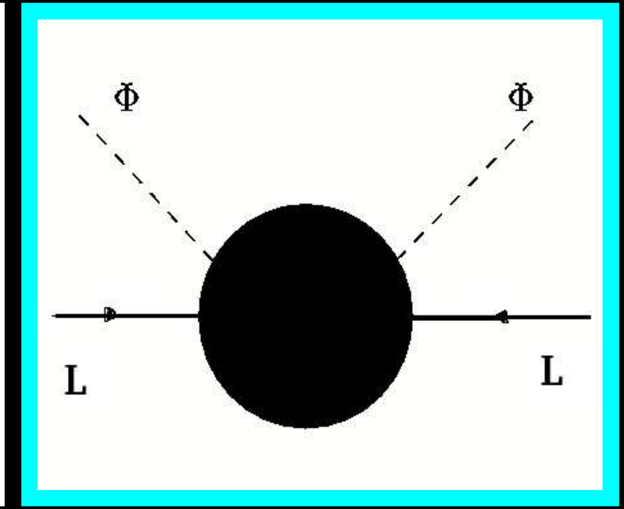


Weinberg PRD22 (1980) 1694

- which scale ⇒
- which flavour structure
- which mechanism **pathways** **many realizations**

MYSTERY REMAINS





Weinberg PRD22 (1980) 1694

- which scale ⇒
- which flavour structure
- which mechanism **pathways** **many realizations**
- **things should be made as simple as possible, but not simpler**
  Albert Einstein

FIN

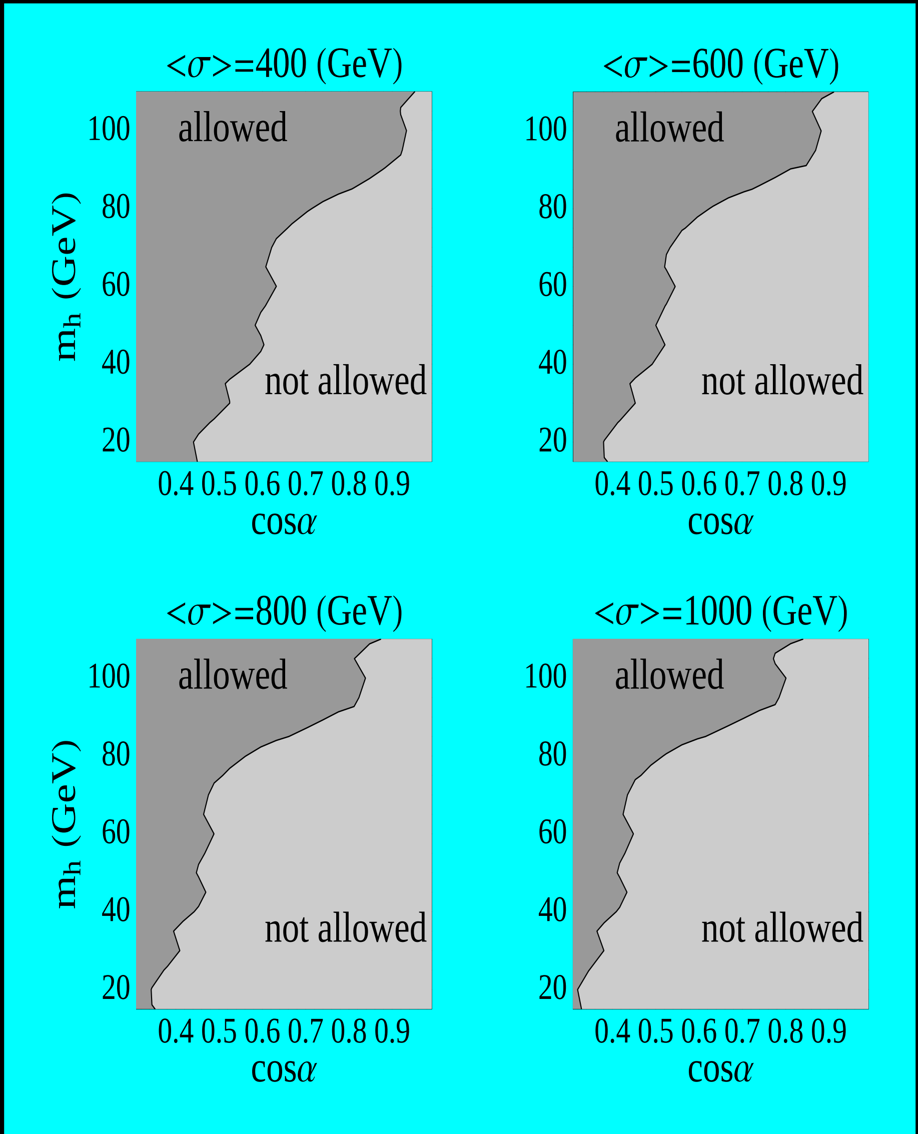
BACKUP SLIDES

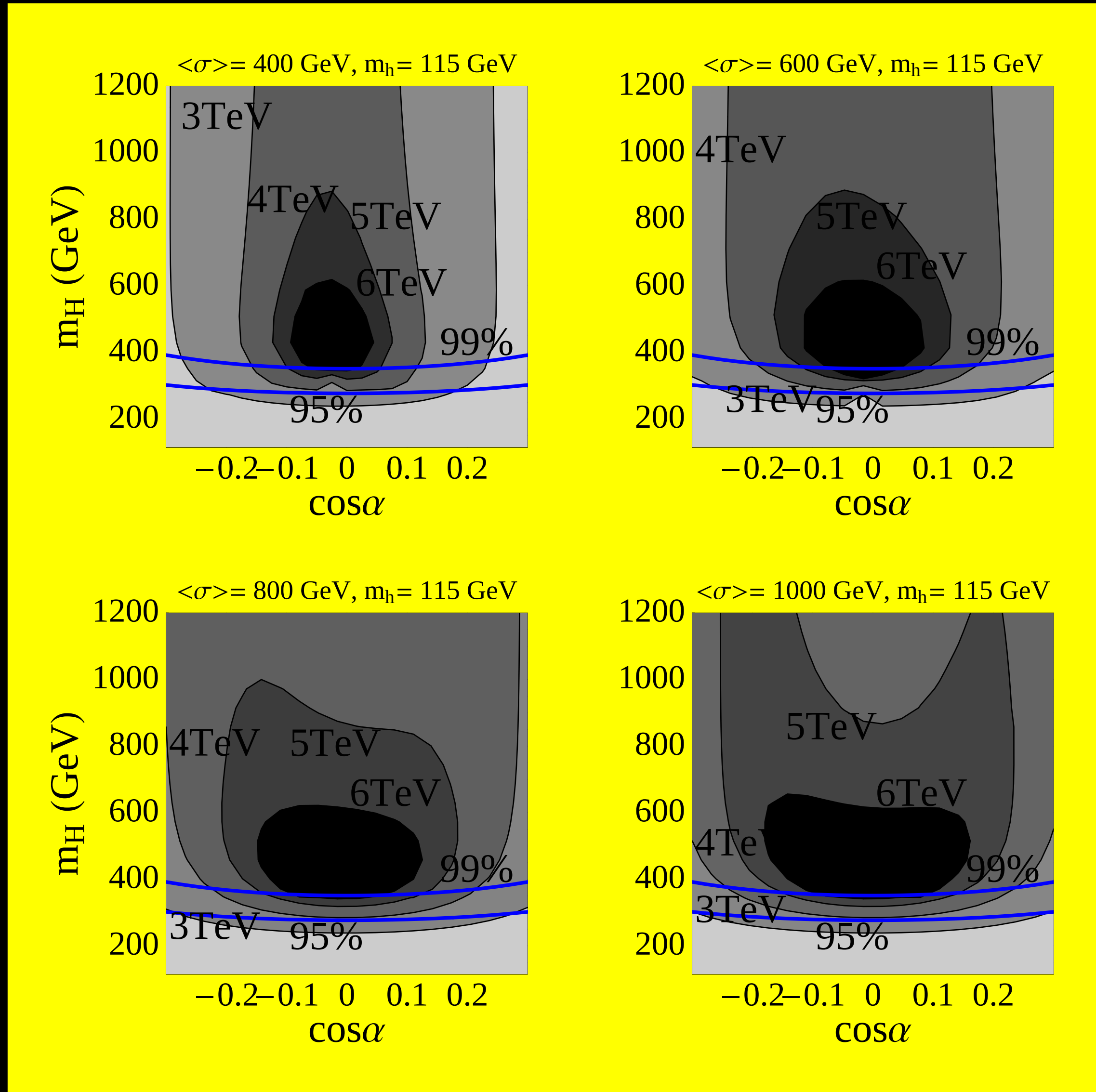
from here on there is no logical order among slides

nu-masses and electroweak symmetry breaking

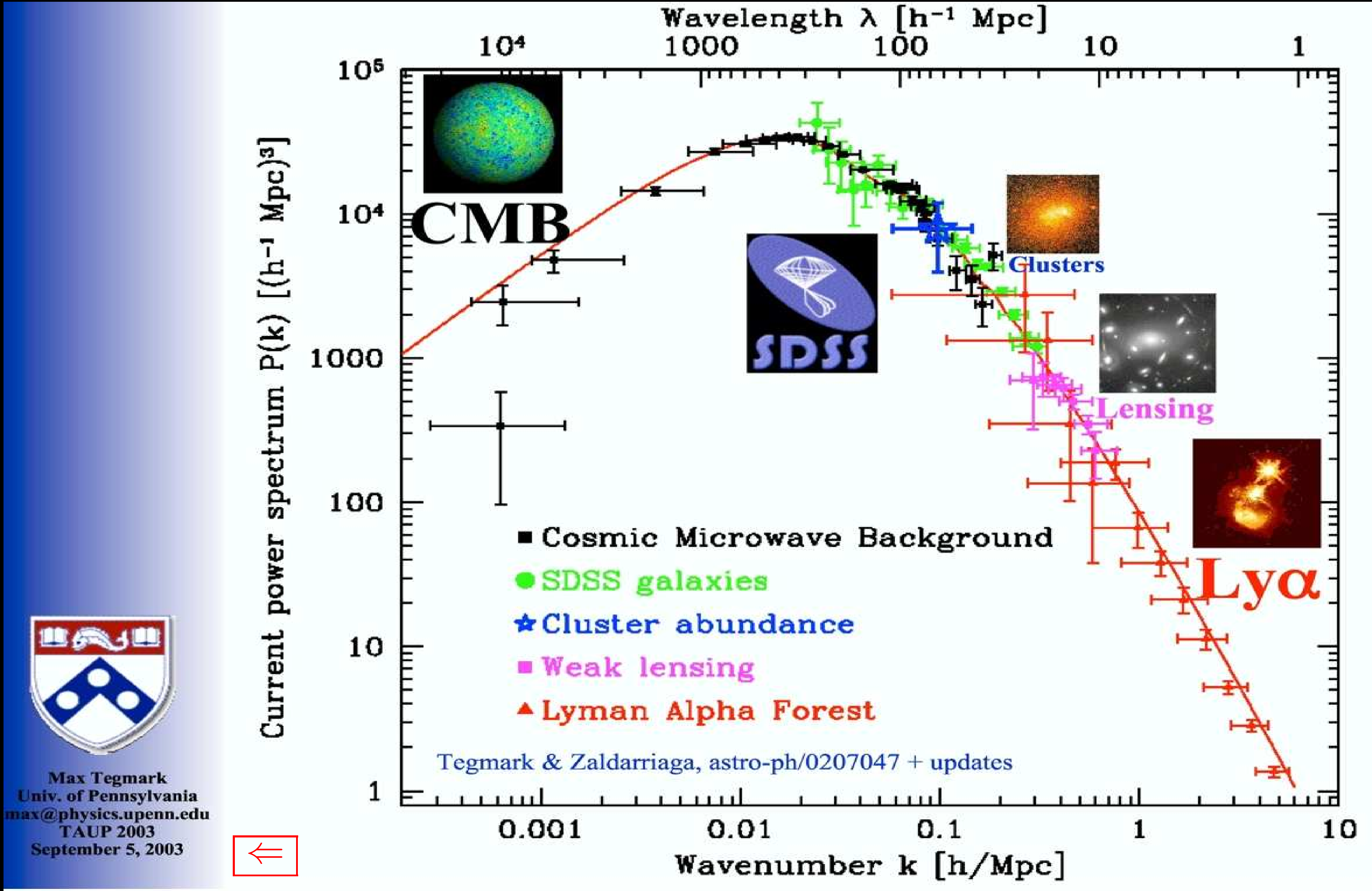
Joshipura & JV, NPB397 (1993) 105

Bazzochi & JV hep-ph/0609093





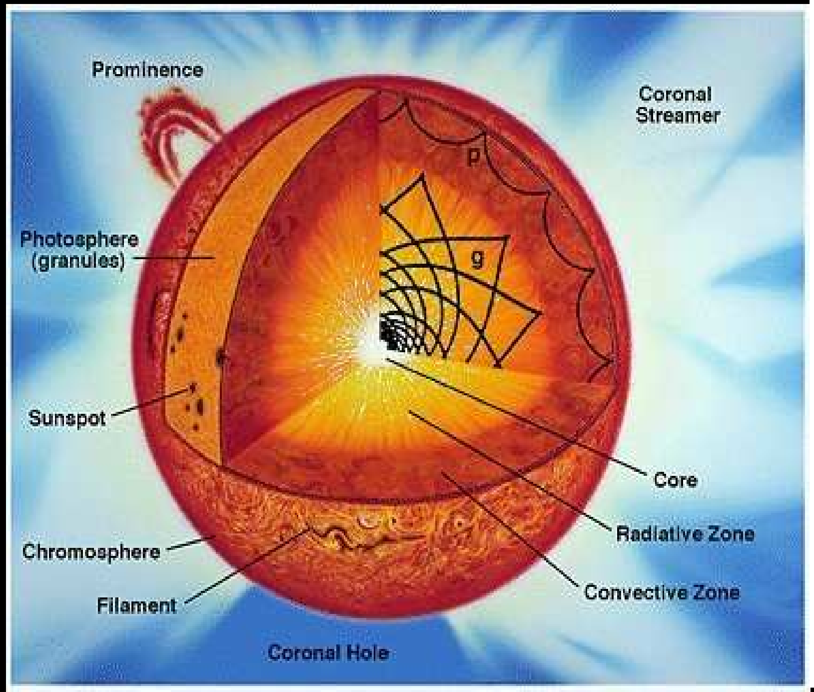
COSMOLOGY AND ABSOLUTE m-nu SCALE

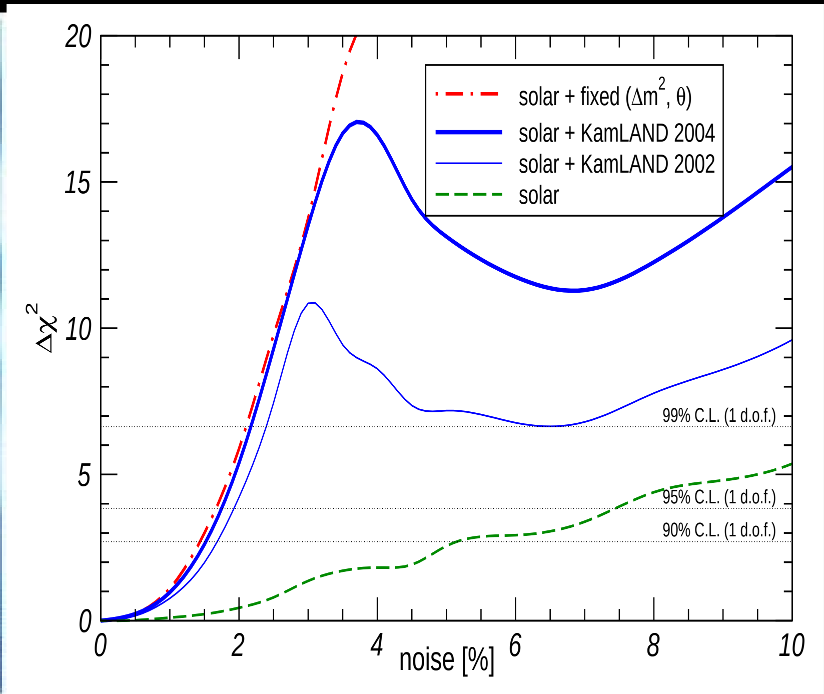


nu-OSCILLATIONS AS DEEP SOLAR PROBE

- e.g. R-zone MHD leads to density fluctuations

Burgess et al, Mon. Not. Roy. Astron.Soc. 348 (2004) 609





- use precision solar-nu data to probe the sun beyond helioseismology contraints ⇐ Burgess et al, Astrophys.J.588 (2003) L65 & JCAP 0401 (2004) 007

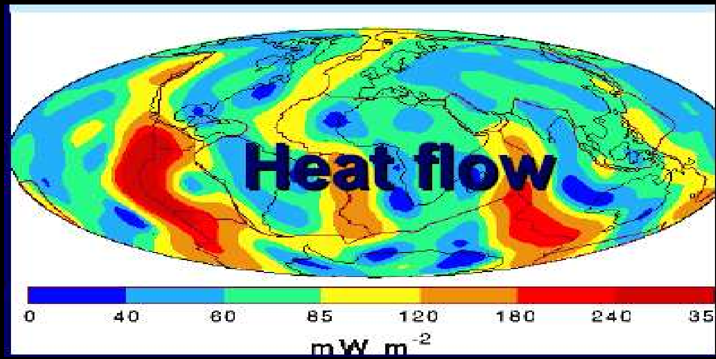
GEO-NEUTRINOS **Rotunno, ...**

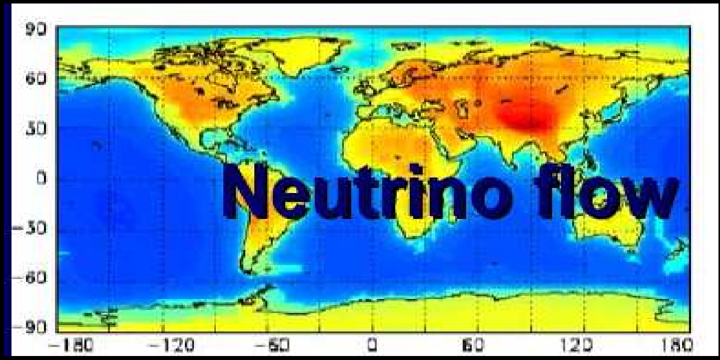
- **neutrinos from natural radioactive decays in the Earth's interior give a 3d map**

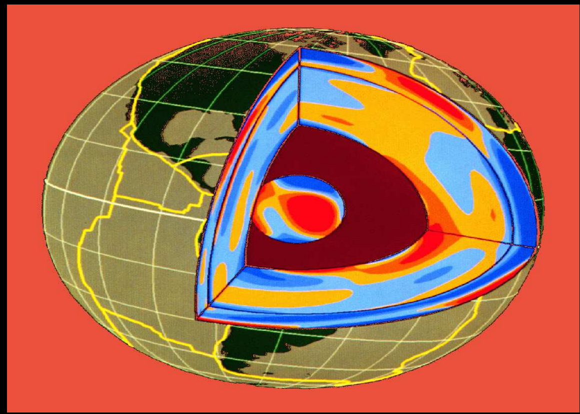
Fiorentini et al ⇐

- **also, Earth matter effect on solar and supernova neutrino oscillations inside the Earth enable in principle reconstruct the Earth's electron number density profile.**

Geotomography with solar and supernova neutrinos, Akhmedov et al JHEP06 (2005) 053







WHERE WE ARE glob $\Leftarrow$

parameter	best fit	2σ	3σ	4σ
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.9	7.3–8.5	7.1–8.9	6.8–9.3
Δm^2_{31} $[10^{-3}\text{eV}^2]$	2.6	2.2–3.0	2.0–3.2	1.8–3.5
$\sin^2\theta_{12}$	0.30	0.26–0.36	0.24–0.40	0.22–0.44
$\sin^2\theta_{23}$	0.50	0.38–0.63	0.34–0.68	0.31–0.71
$\sin^2\theta_{13}$	0.000	≤ 0.025	≤ 0.040	≤ 0.058

Table I: **THREE–NEUTRINO OSCILLATION PARAMETERS-2006**. Best-fit values, 2σ, 3σ, and 4σ intervals (1 d.o.f.) for the 3-nu neutrino oscillation parameters from global data from solar, atmospheric, reactor (KamLAND and CHOOZ) and accelerator (K2K and MINOS) experiments.

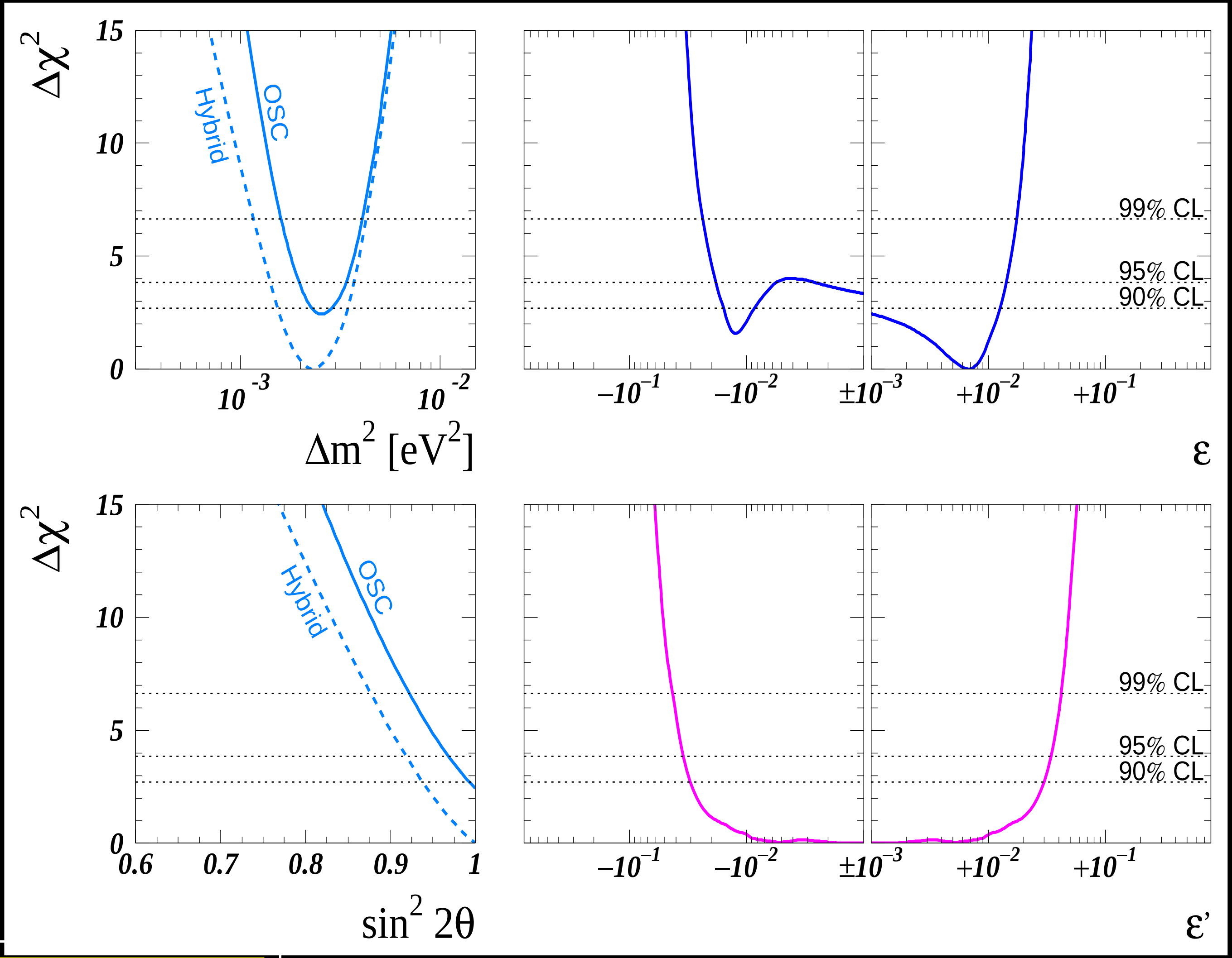
http://ahep.uv.es/ M. Maltoni et al, NJP 6 (2004) 122 = hep-ph/0405172 v5

ROBUSTNESS OF ATM-NU

glbal view

atm bounds on FC and NU nu-interactions

upd of Fornengo et al, PRD65 (2002) 013010



(1-d Bartol)

will improve at NuFact

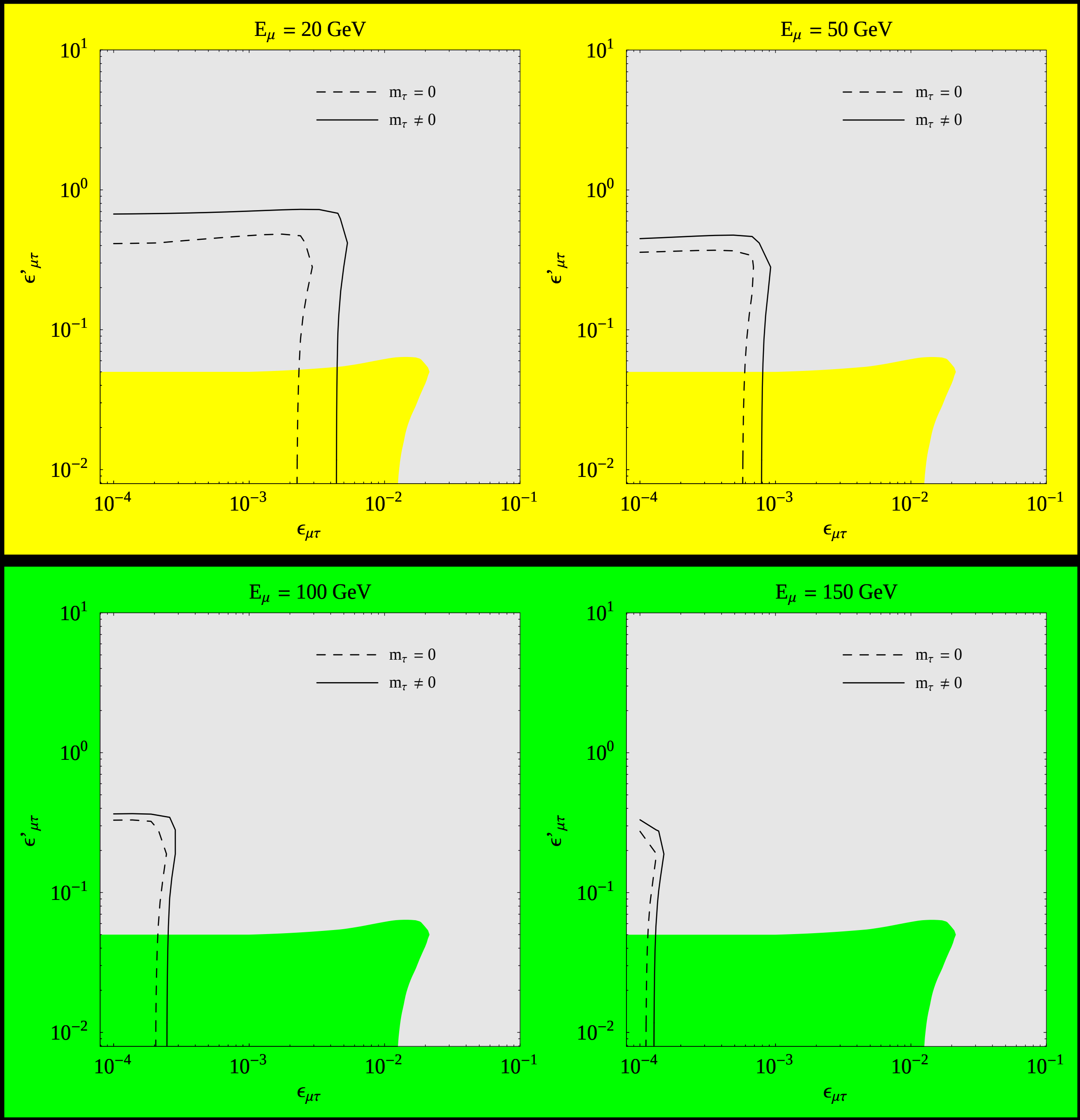
(3-g) Friedland, Lunardini & Maltoni hep-ph/0408264

FC-NSI-tests at generic NuFact ☉

10 kt detector,
0.33 ν_τ detection efficiency above 4 GeV; no tau charge id needed

improved FC test

Huber & JV PLB523 (2001) 151

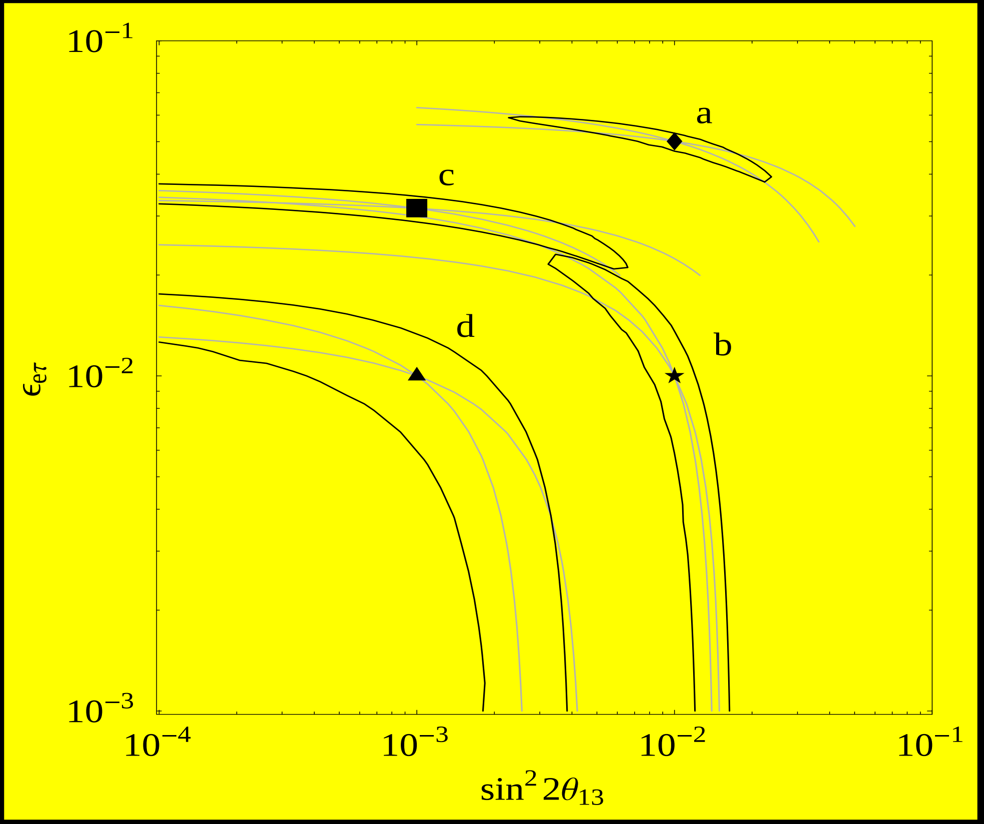


FCI-oscillation CONFUSION THEOREM

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

Huber et al, PRL88 (2002) 101804

& PRD66 (2002) 013006



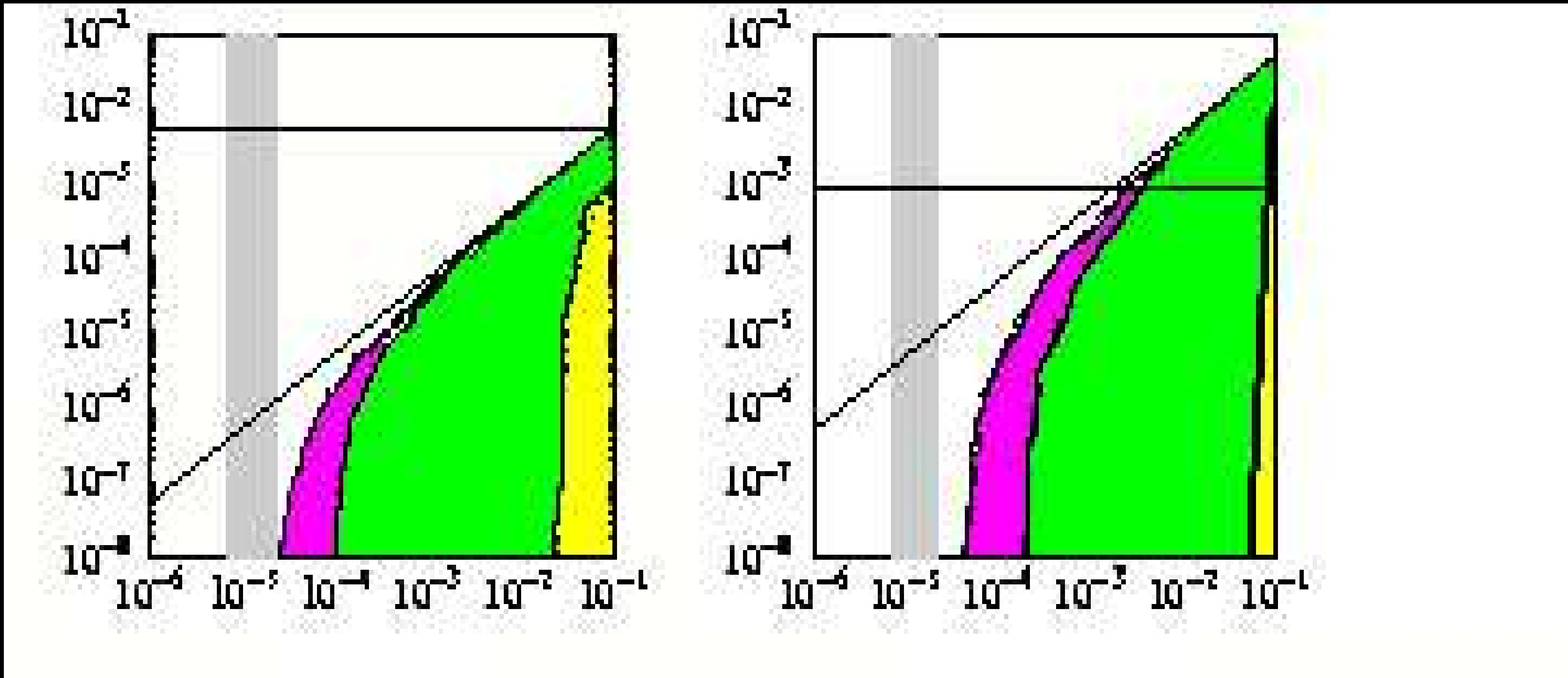
near-site programme essential

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 et al, PRD66, 013006 (2002)

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



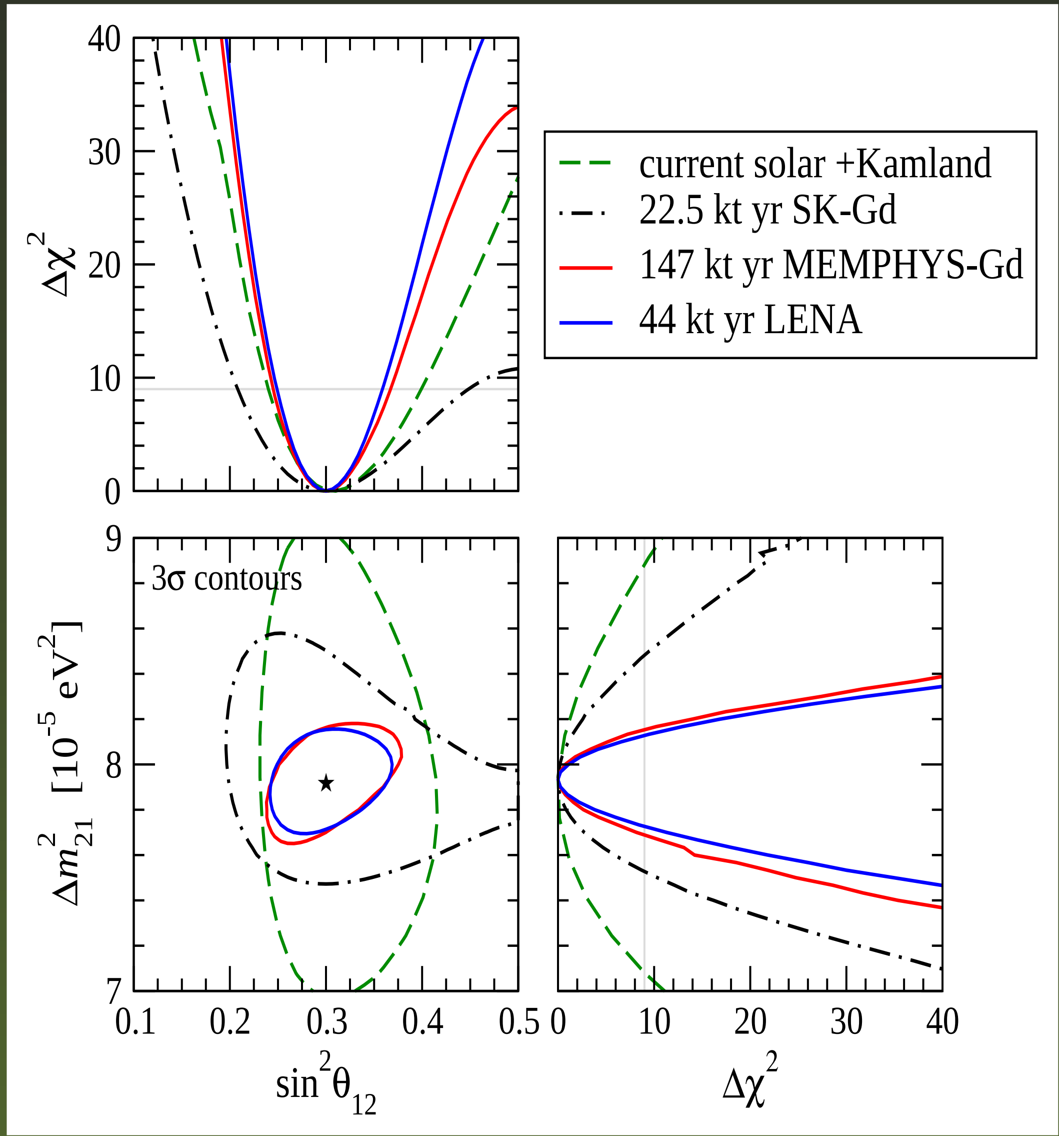
baselines 700 km 3 000 km 7 000 km

horizontal black line is current NSI limit vertical grey band: sensitivity without NSI

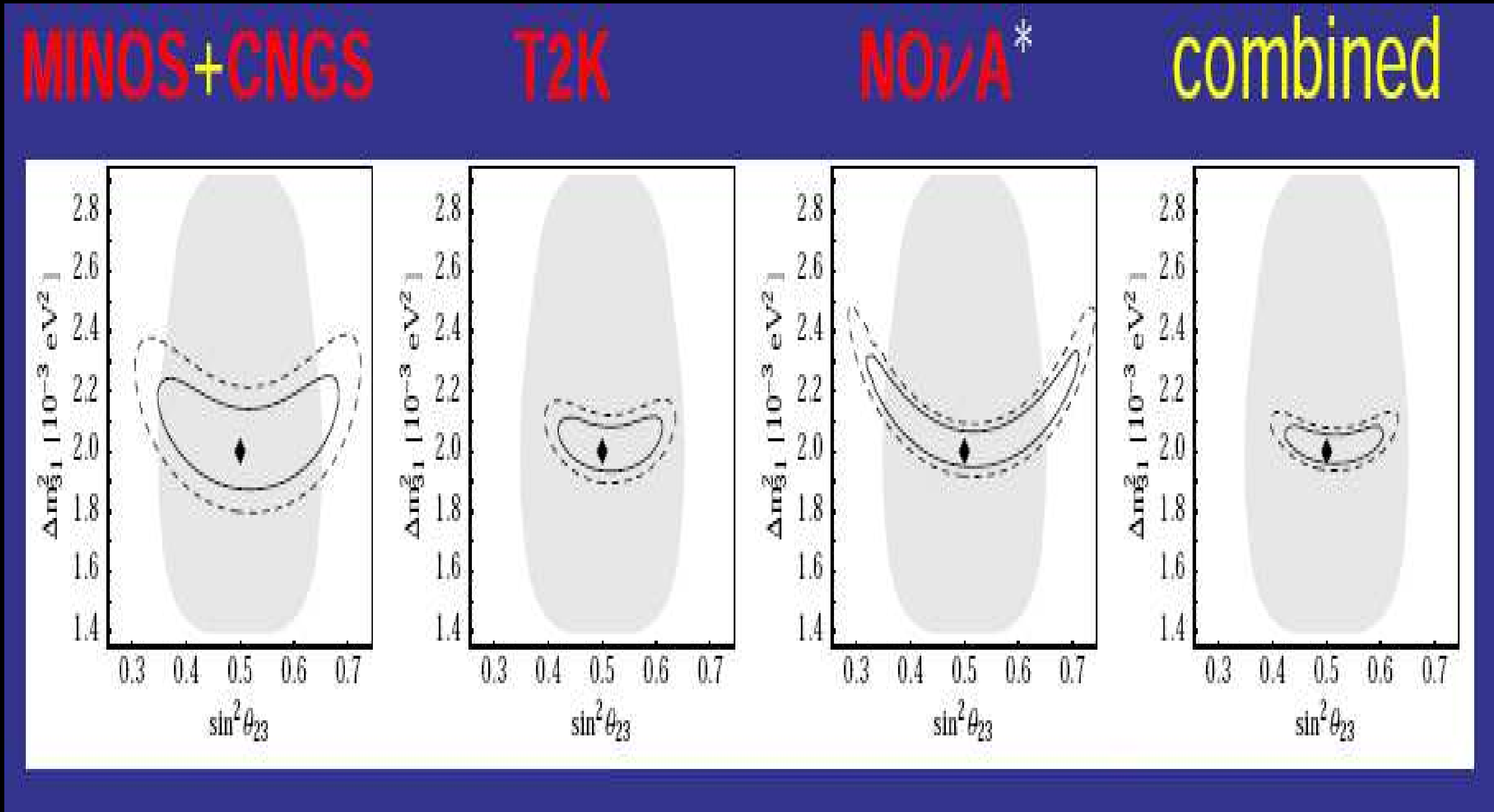
improving on solar parameters

long-baseline expt using french reactors & a detector in Frejus underground lab

courtesy of T. Schwetz



IMPROVING ON ATM PARAMETERS



Huber et al PRD70 (2004) 073014 also CERN-MEMPHYS Campagne et al hep-ph/0603172

need long-baseline accelerator expts eg T2K •

PATHWAYS TO NU-MASS

- top-down vs bottom-up

PATHWAYS TO NU-MASS ●

- top-down vs bottom-up
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...

PATHWAYS TO NU-MASS ●

- top-down vs bottom-up
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...
- what is the scale ?
  - GUT scale seesaw with low B-L scale
  - Intermediate scale seesaw: P-Q, L-R ...
  - Weak scale (inverse) seesaw

PATHWAYS TO NU-MASS ●

- top-down vs bottom-up
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...
- what is the scale ?
  - GUT scale seesaw with low B-L scale
  - Intermediate scale seesaw: P-Q, L-R ...
  - Weak scale (inverse) seesaw
- a theory of flavour?

PATHWAYS TO NU-MASS

- top-down vs bottom-up
- what is the mechanism?
  - tree vs radiative
  - B-L gauged vs ungauged...
- what is the scale ?
  - GUT scale seesaw with low B-L scale
  - Intermediate scale seesaw: P-Q, L-R ...
  - Weak scale (inverse) seesaw
- a theory of flavour?
- phenomenological m-nu hints other than oscillations?

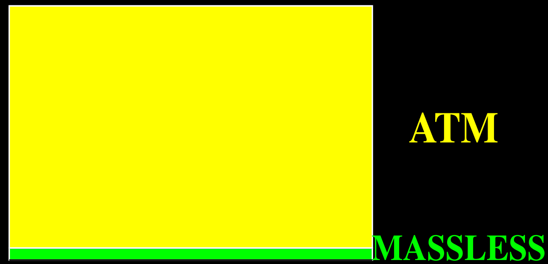
  "generic": LFV $\mu \to e\gamma$, $\tau \to \mu\gamma$, mu-e conversion in nuclei, ...

  "specifi c: $\beta\beta_{0\nu}$, $m_\nu \geq 0.3$ eV, light slepton...

  "smoking gun": testing nu-mixing at LHC?

NU–MASSES FROM LOW–ENERGY SUSY?

- **weak-scale seesaw** **atm scale**

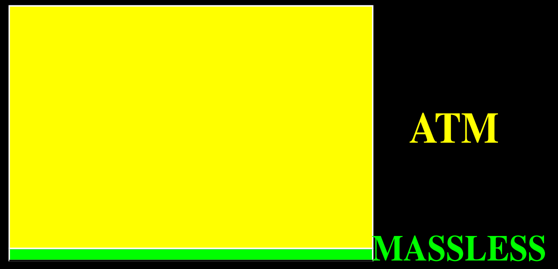


Diaz etal PRD68 (2003) 013009, PRD62 (2000) 113008; D65 (2002) 119901; PRD61 (2000) 071703

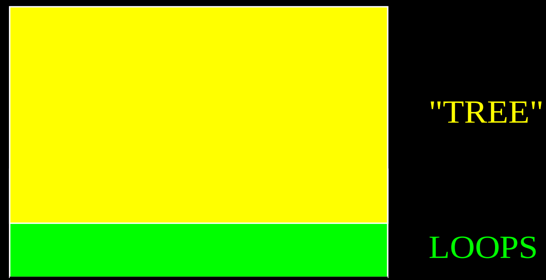
theoretical origin

models with spont RPV: Masiero and Valle, PLB251 (1990) 273

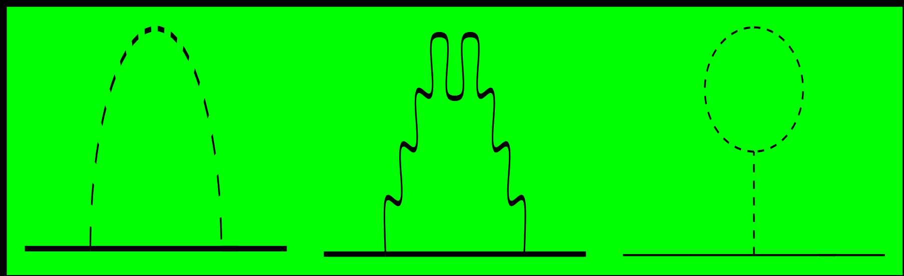
NU–MASSES FROM LOW–ENERGY SUSY?



- **weak-scale seesaw atm scale**



- **radiative solar mass scale**



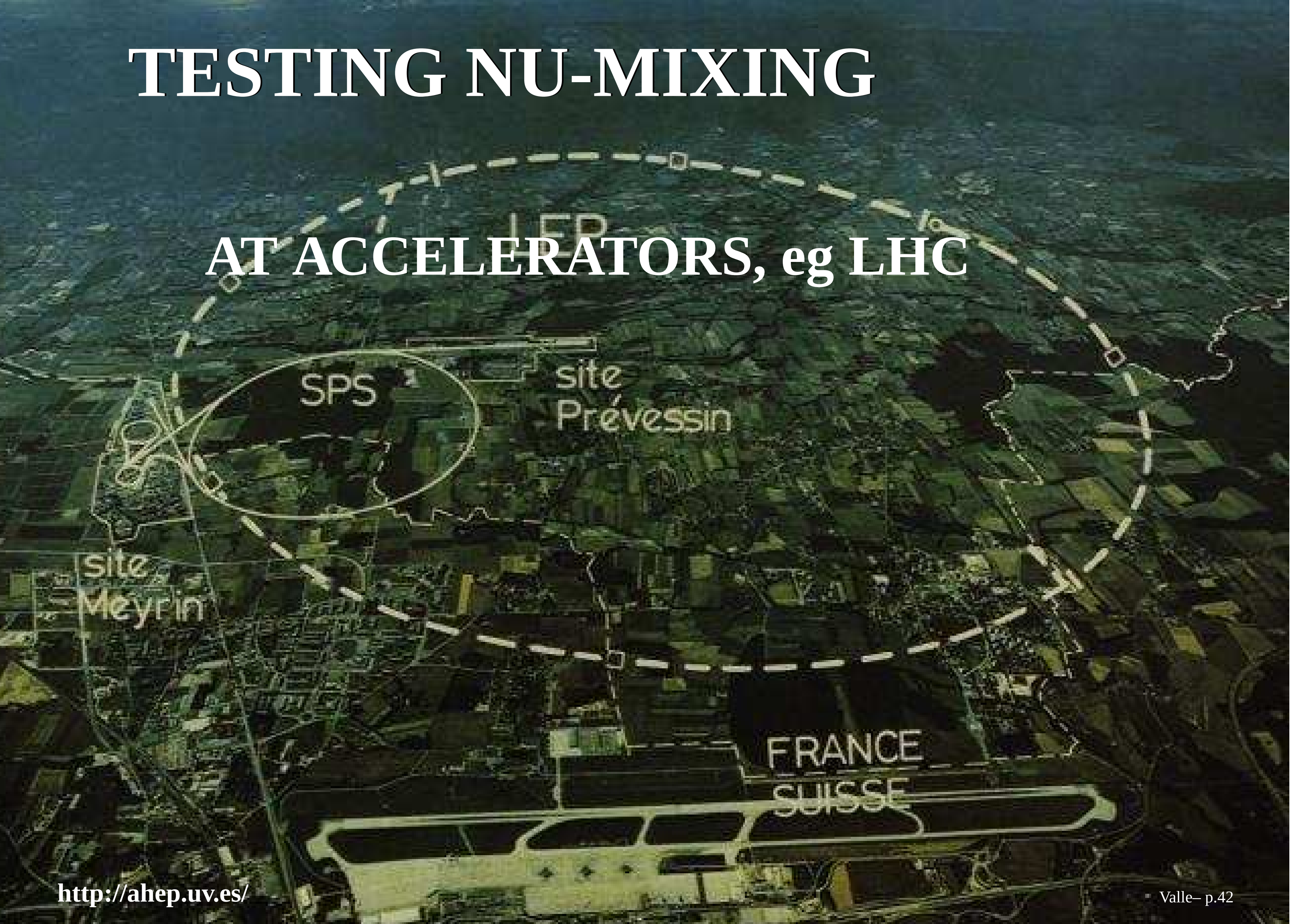
Diaz etal PRD68 (2003) 013009, PRD62 (2000) 113008; D65 (2002) 119901; PRD61 (2000) 071703

theoretical origin

models with spont RPV: Masiero and Valle, PLB251 (1990) 273

TESTING NU-MIXING

AT ACCELERATORS, eg LHC



TESTING NU–MIXING ANGLES at LHC/ILC

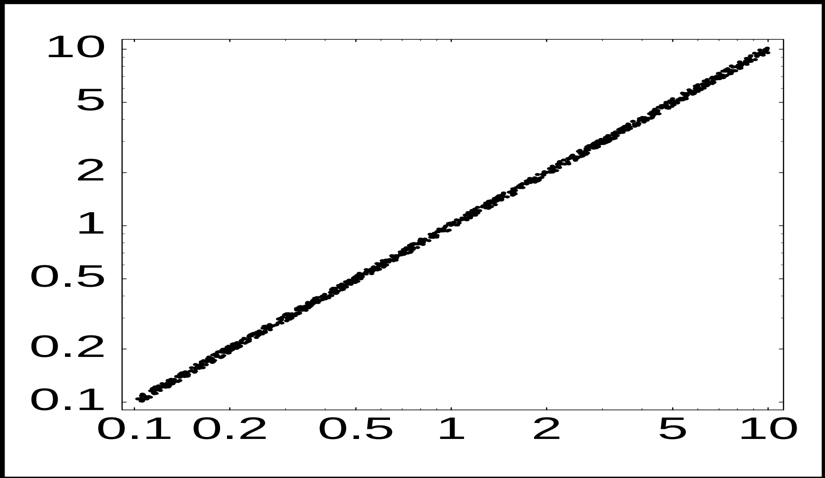
- **LSP decays lead to double vertices, e.g. at Tevatron**

de Campos et al, PRD71 (2005) 075001

  - **LSP decay properties correlate with nu-mixing angles**

    LHC will provide enough luminosity for detailed correlation studies

    smoking gun test of SUSY origin of nu-mass **Porod et al PRD63 (2001) 115004**



$\frac{BR(\chi\to\mu W)}{BR(\chi\to\tau W)}$ **vs** $\tan^2_{\rm atm}$

TESTING NU–MIXING ANGLES at LHC/ILC

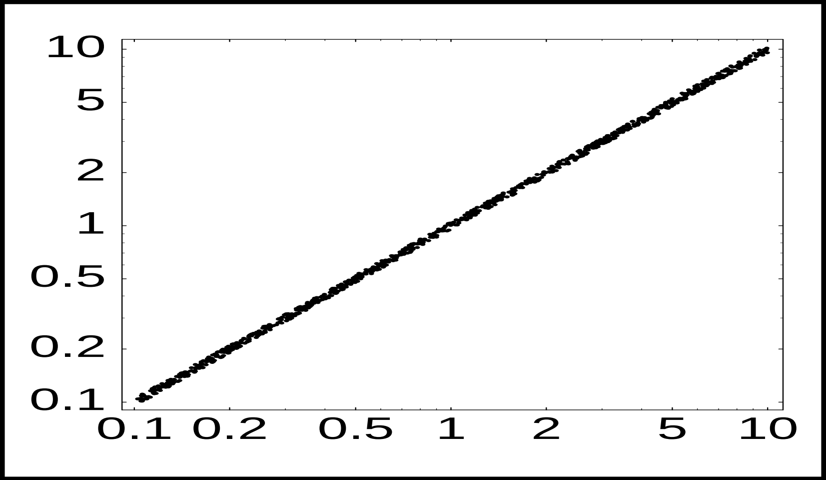
- LSP decays lead to **double vertices**, e.g. at Tevatron

de Campos et al, PRD71 (2005) 075001

  - LSP decay properties correlate with nu-mixing angles

    LHC will provide enough luminosity for detailed **correlation studies**

    smoking gun test of SUSY origin of nu-mass Porod et al PRD63 (2001) 115004



$\frac{BR(\chi\to\mu W)}{BR(\chi\to\tau W)}$ vs $\tan^2_{\rm atm}$

  - irrespective of the nature of the LSP

stop Restrepo et al, PRD64 (2001) 055011

stau Hirsch et al, PRD66 (2002) 095006

others D68 (2003) 115007

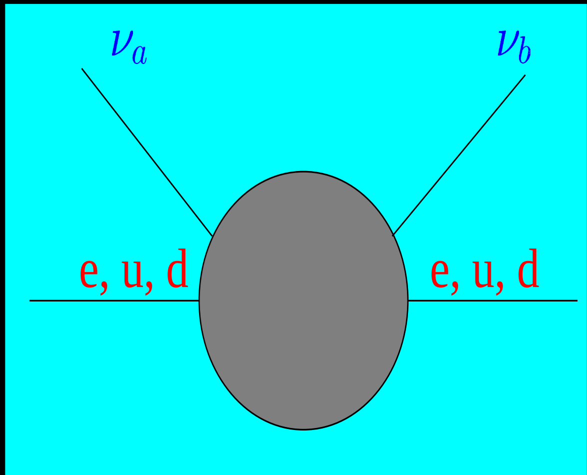
model-independent SEESAW, CC, NC & NSI

Schechter, JV, PRD22 (1980) 2227 & D25 (1982) 774

- **scale need not be high** since # of $\mathrm{SU}(2) \otimes \mathrm{U}(1)$ singlets is arbitrary
- **far more angles and phases** than for quarks

  (i) Majorana phases

  (ii) isodoublet-isosinglet mixing angles
- **lepton mixing effectively non-unitary**

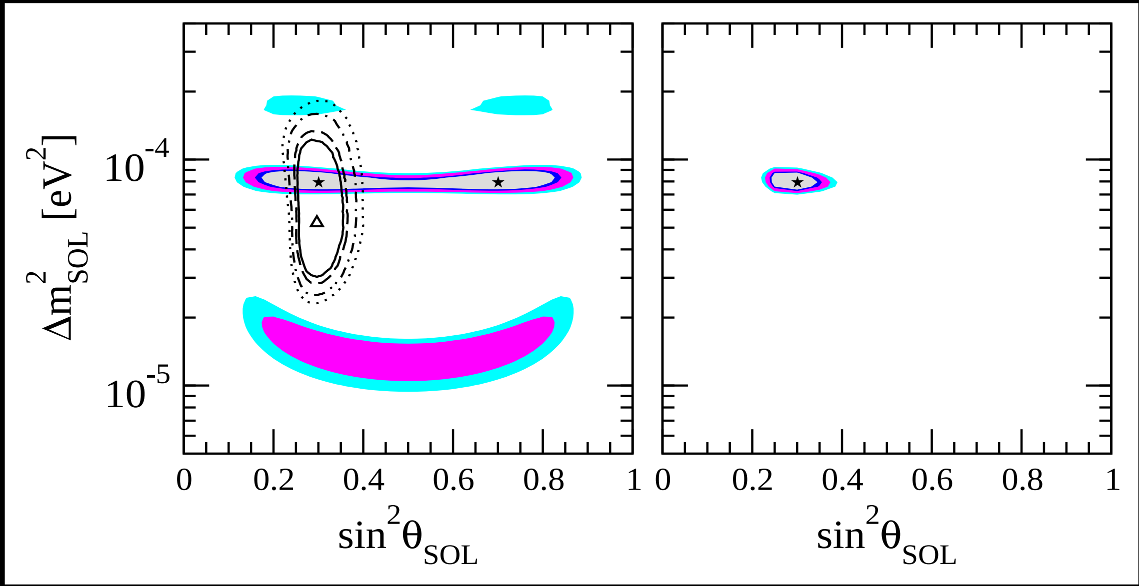


LMM $\Leftarrow$ SS $\Leftarrow$

- **CC & NC source of gauge-induced NSI**

FRAGILITY OF SOLAR-NU?

wrt NSI



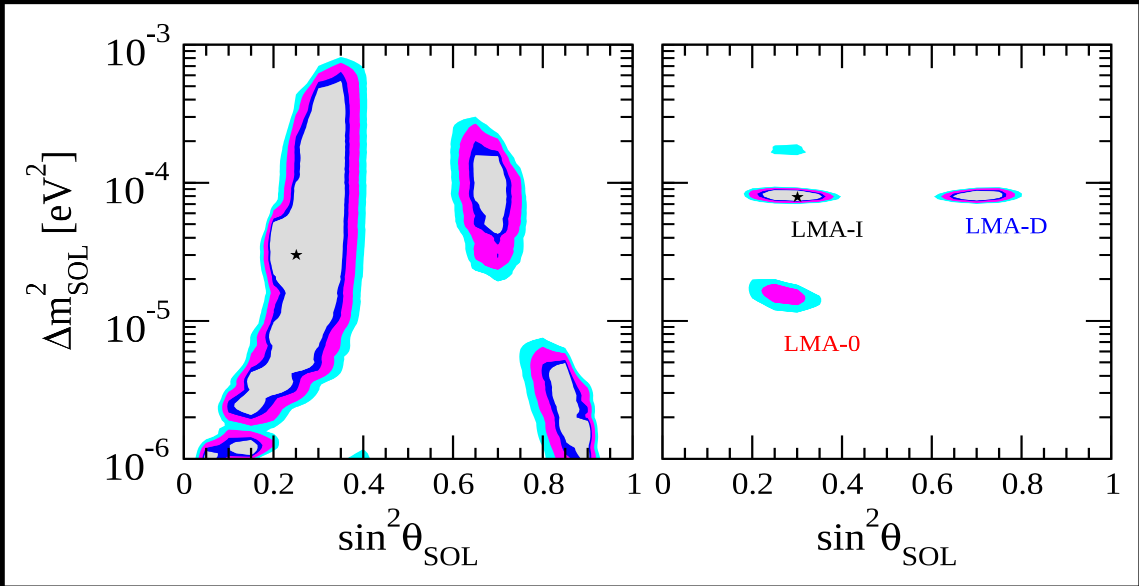
Miranda etal, hep-ph/0406280

JHEP 2006

Glbview

degenerate dark-side soln, unresolved by KamLAND

NSI



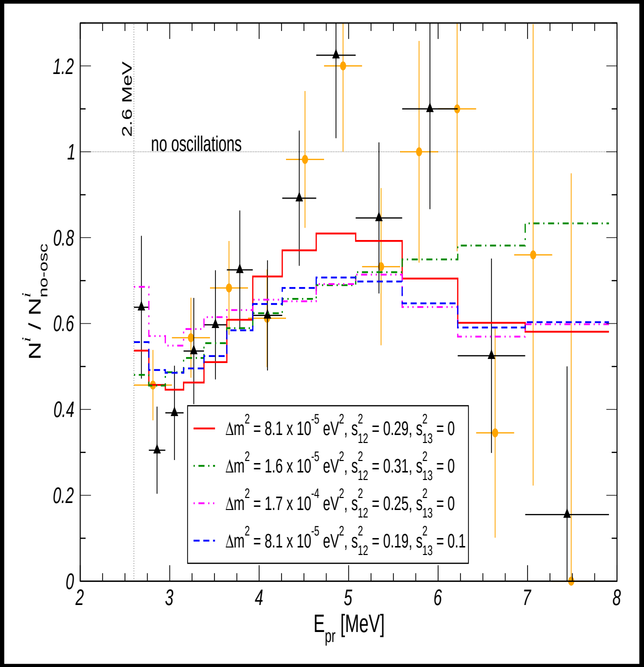
resolve

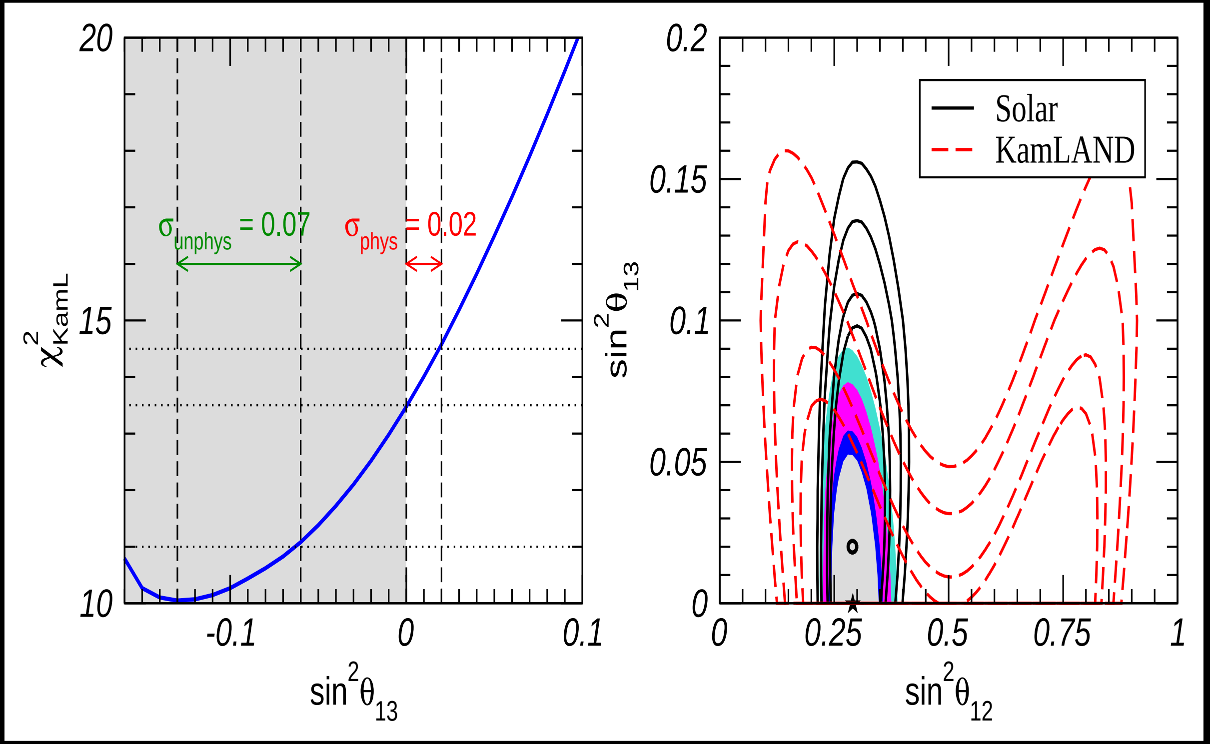
why KamLAND04 improves θ_{13}

⇐

strong spectrum distortion

favors unphysical θ_{13} values





combination with solar further improves ...

Robustness of solar-nu oscillations wrt noise-KL04

neutrino propagation strongly affected by solar density noise

Balantekin et al 95

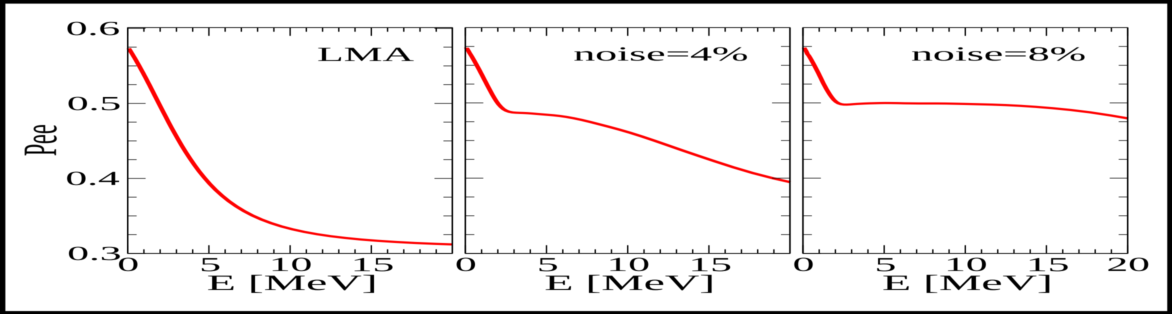
Nunokawa et al NPB472 (1996) 495

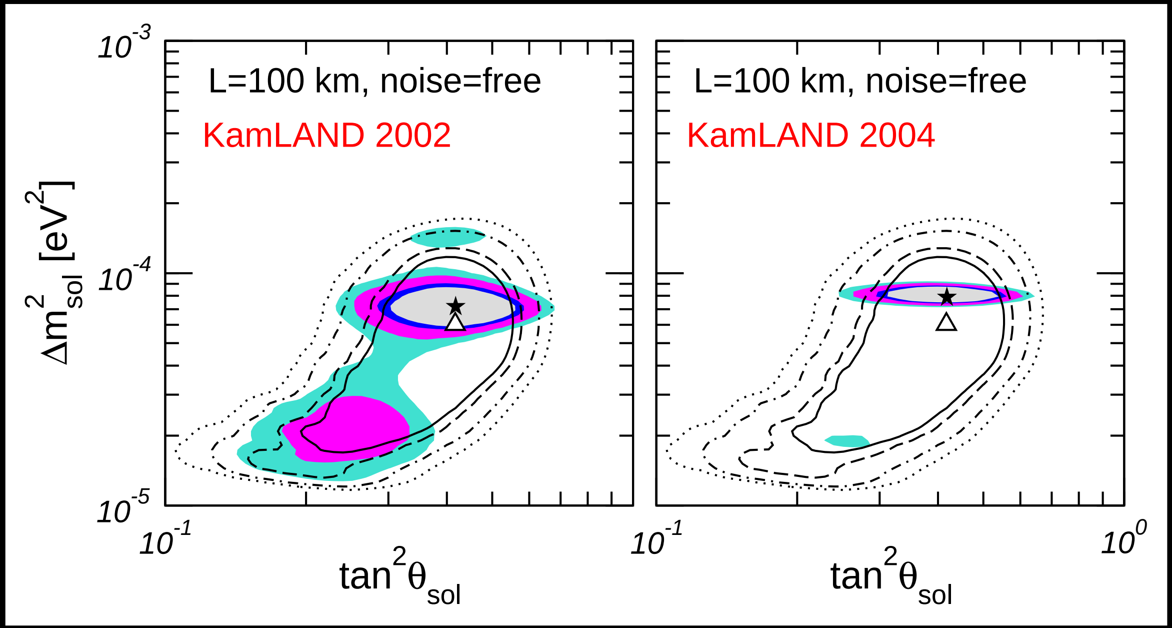
Burgess et al 97

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

& JCAP 0401 (2004) 007

Guzzo et al, Balantekin et al





despite such large distortion

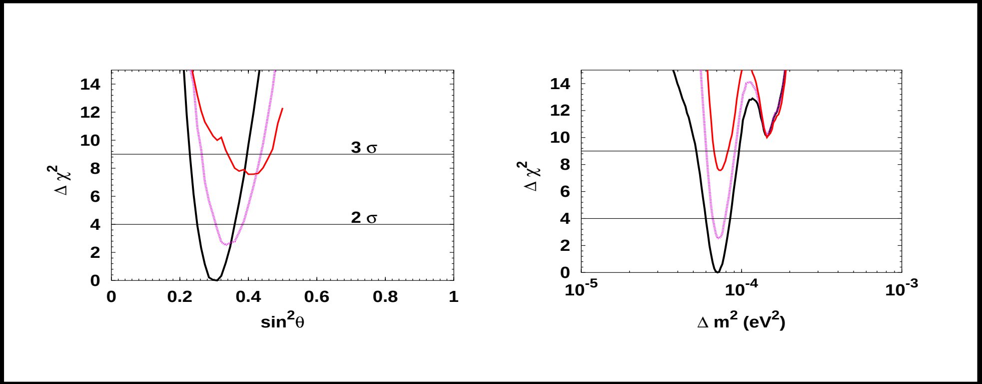
determination is robust

Maltoni et al, hep-ph 0405172

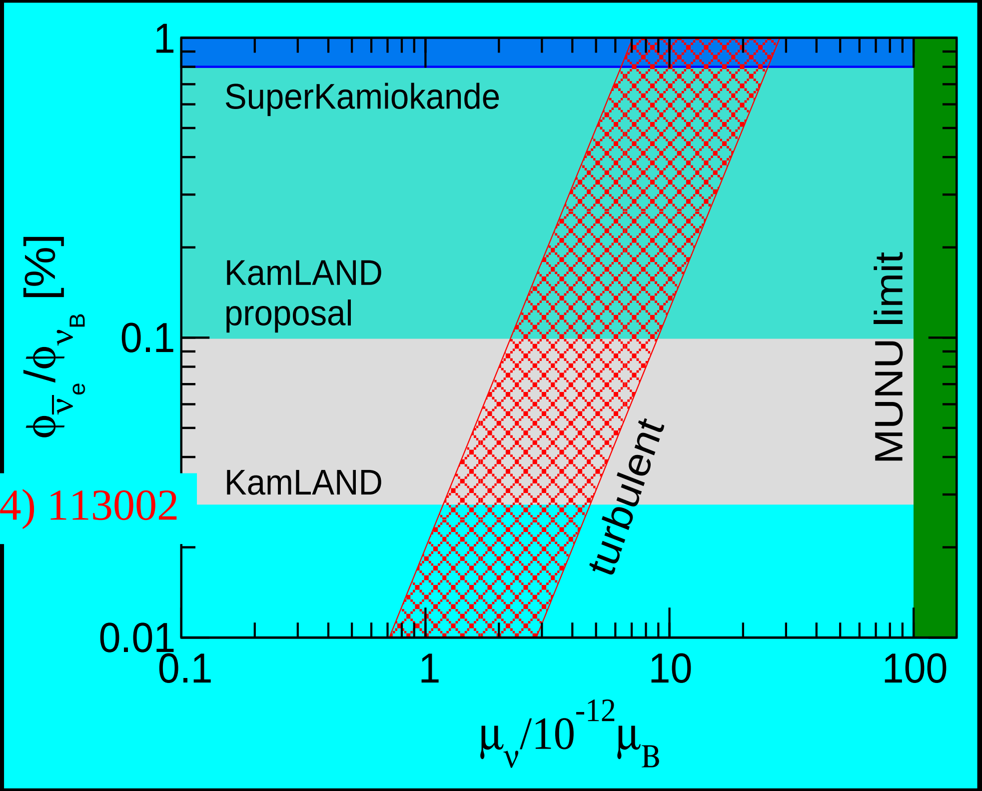
noisy Sun

ROBUSTNESS of SOLAR-nu oscillations wrt SFP

ensured by absence of solar anti-nu



regular versus random mag field



isolating μ_ν from $\mu_\nu B$?

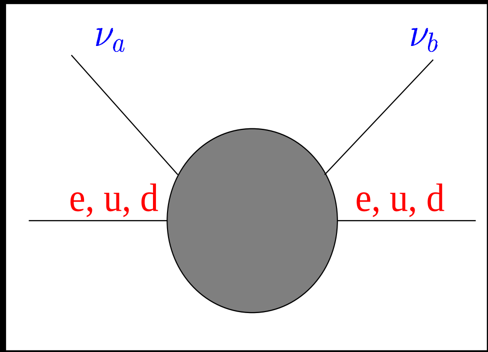
Miranda et al PRL93 (2004) 051304 & PRD70 (2004) 113002

⇐SFP

NON-STANDARD INTERACTIONS

⇐ Frag

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



can induce non-standard interactions

oscillations of massless neutrinos in matter, which are E-independent, conver
both neutrinos & anti-nu's, can be resonant in SNovae

Wolfenstein; Valle PLB199 (1987) 432

Roulet 91; Guzzo et al 91; Barger et al 91,...

they give excellent description of solar data Guzzo et al NPB629 (2002) 479

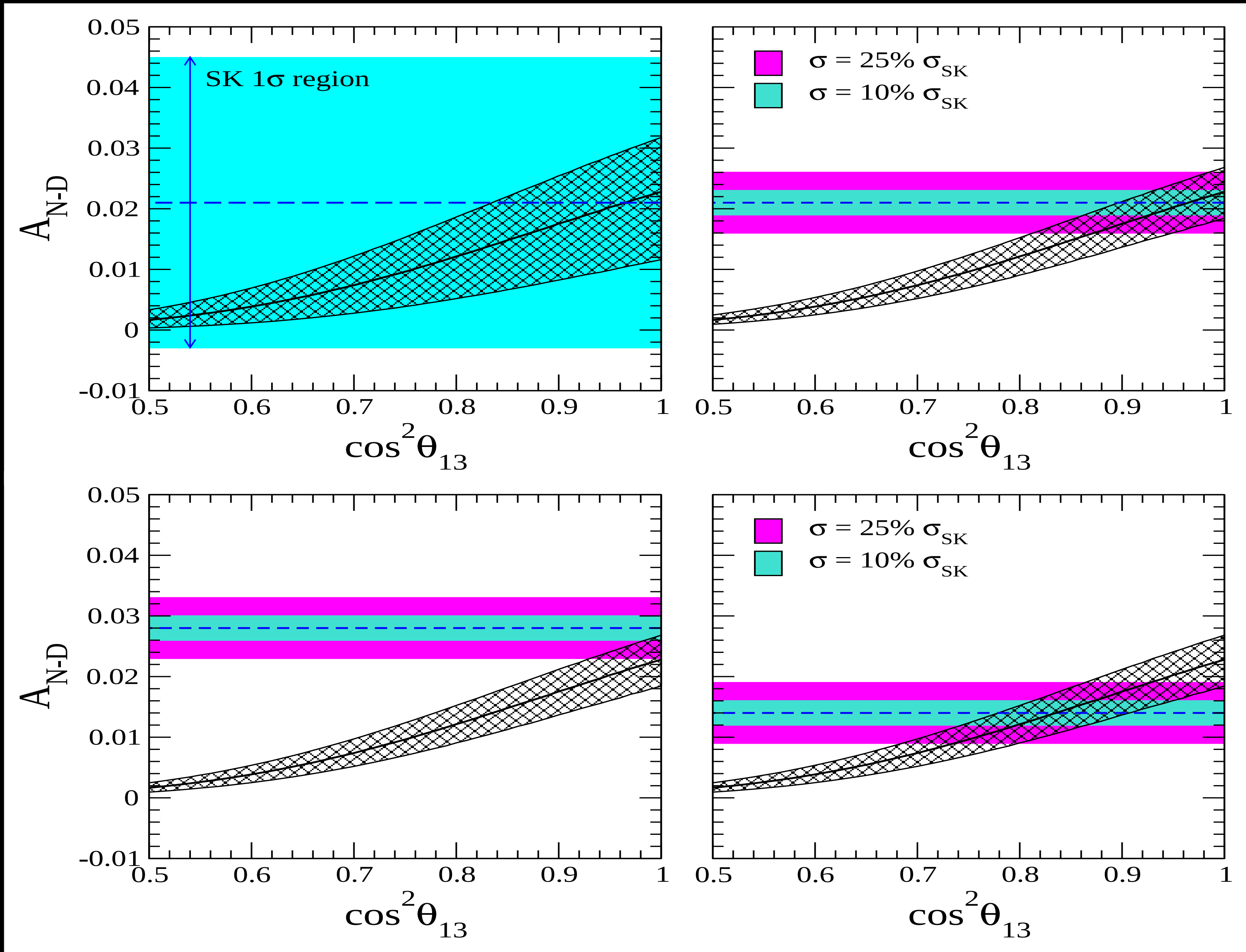
but can not be the leading mechanism, due to KamLAND

. lead to new dark-side solar neutrino oscill solution

DAY-NIGHT EFFECT WITH 3 NEUTRINOS

Akhmedov, Tortola, JV, JHEP05 (2004) 057

⇐

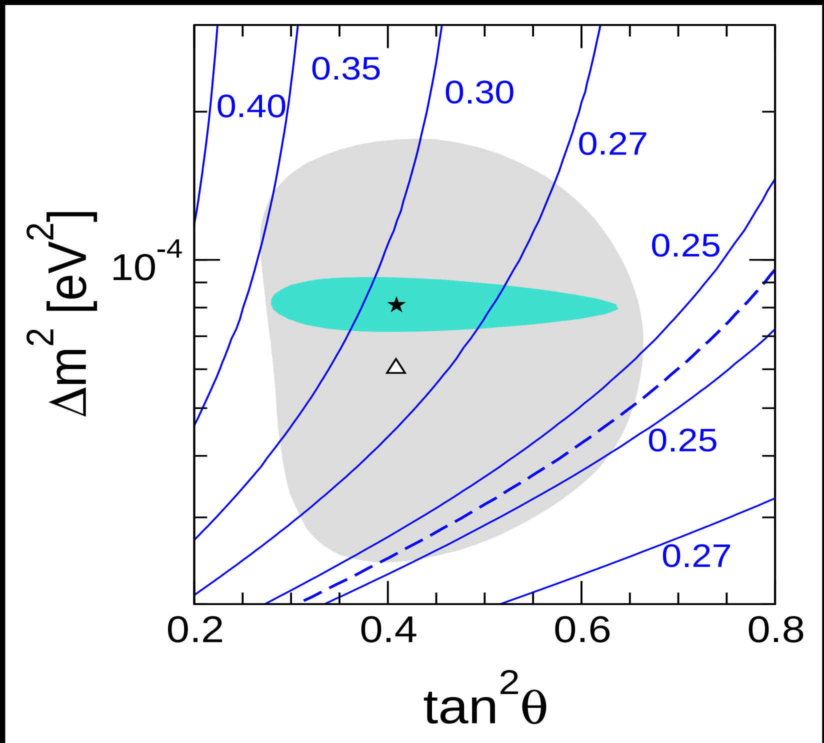


LOW ENERGY NEUTRINOS

two tasks for Borexino? KamLAND?

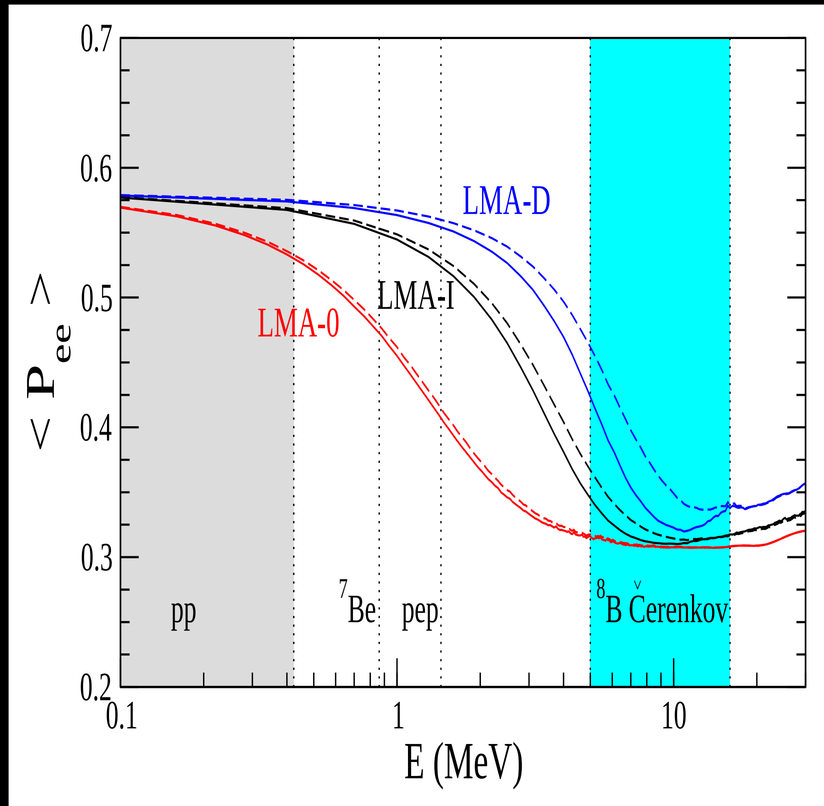
• probe nu-magn moment

upd of Grimus et al, NPB648, 376 (2003)



• probe NSI

Miranda et al hep-ph/0406280 JHEP



NSI-frag

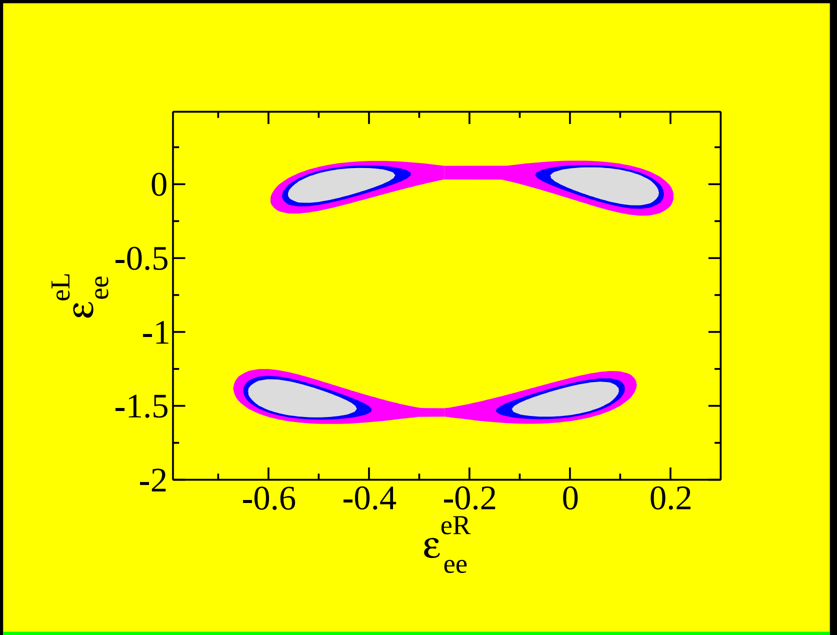
new frontier ... θ_{13}, new neutral gauge bosons, etc ⇐

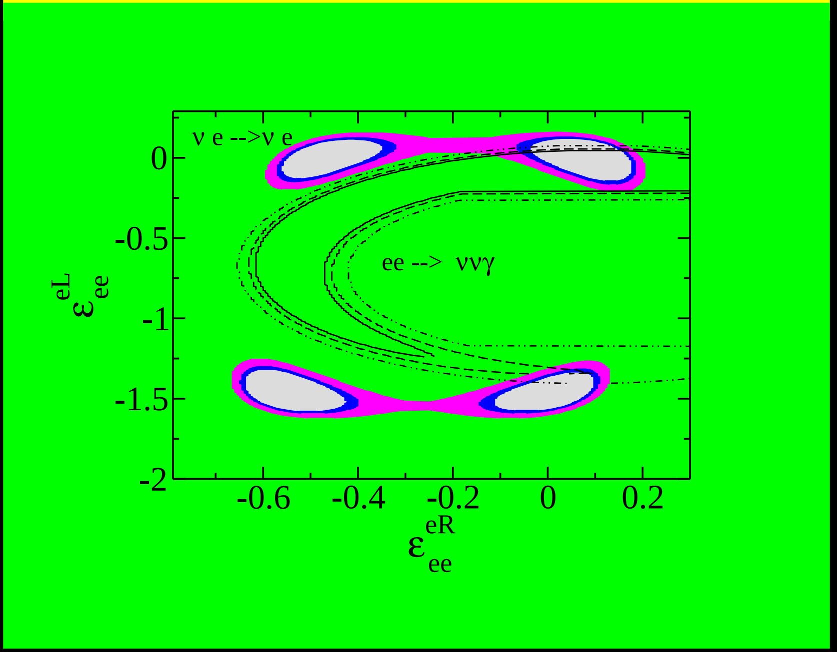
NSI with electrons

$\nu - e$ scattering constrains NSI parameters up to four-fold degeneracy (even with just two NU free parameters) Barranco et. al. PRD73 (2006) 113001

can $ee \to \nu\nu\gamma$ from LEP help?

Barranco et. al. in preparation $\Rightarrow$

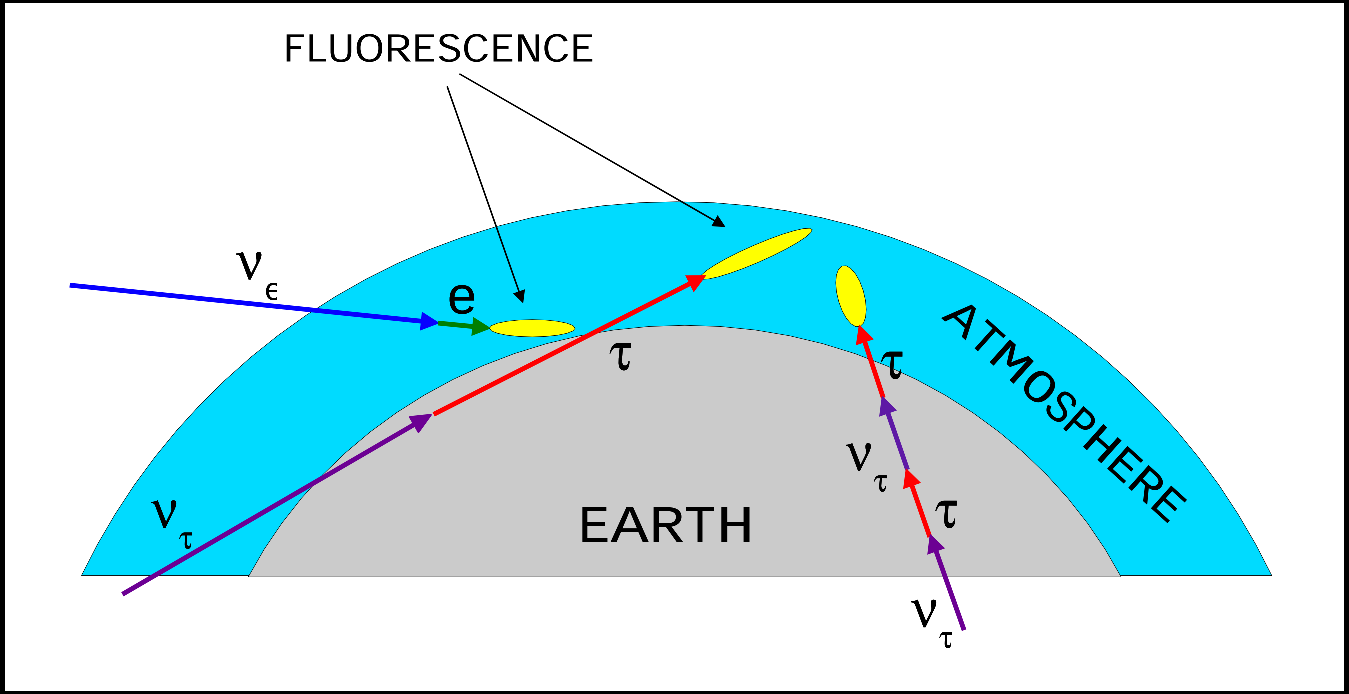




COMBINING TECHNIQUES

- ground-based detection of high energy particles through their interaction with water
- track development of air showers by observing ultraviolet light emitted high in the Earth's atmosphere.

⇐



HIGH ENERGY ASTROPHYSICS