NEUTRINOS AS MESSENGERS IN ASTROPARTICLE PHYSICS

José W. F. Valle

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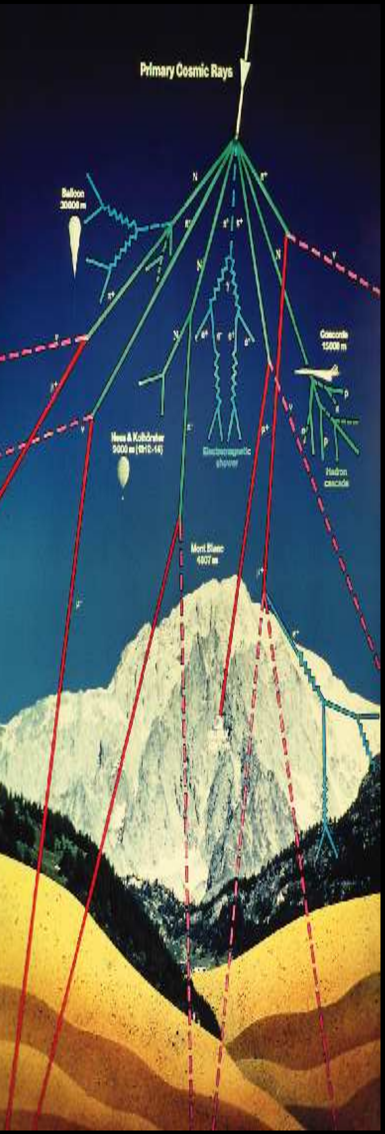
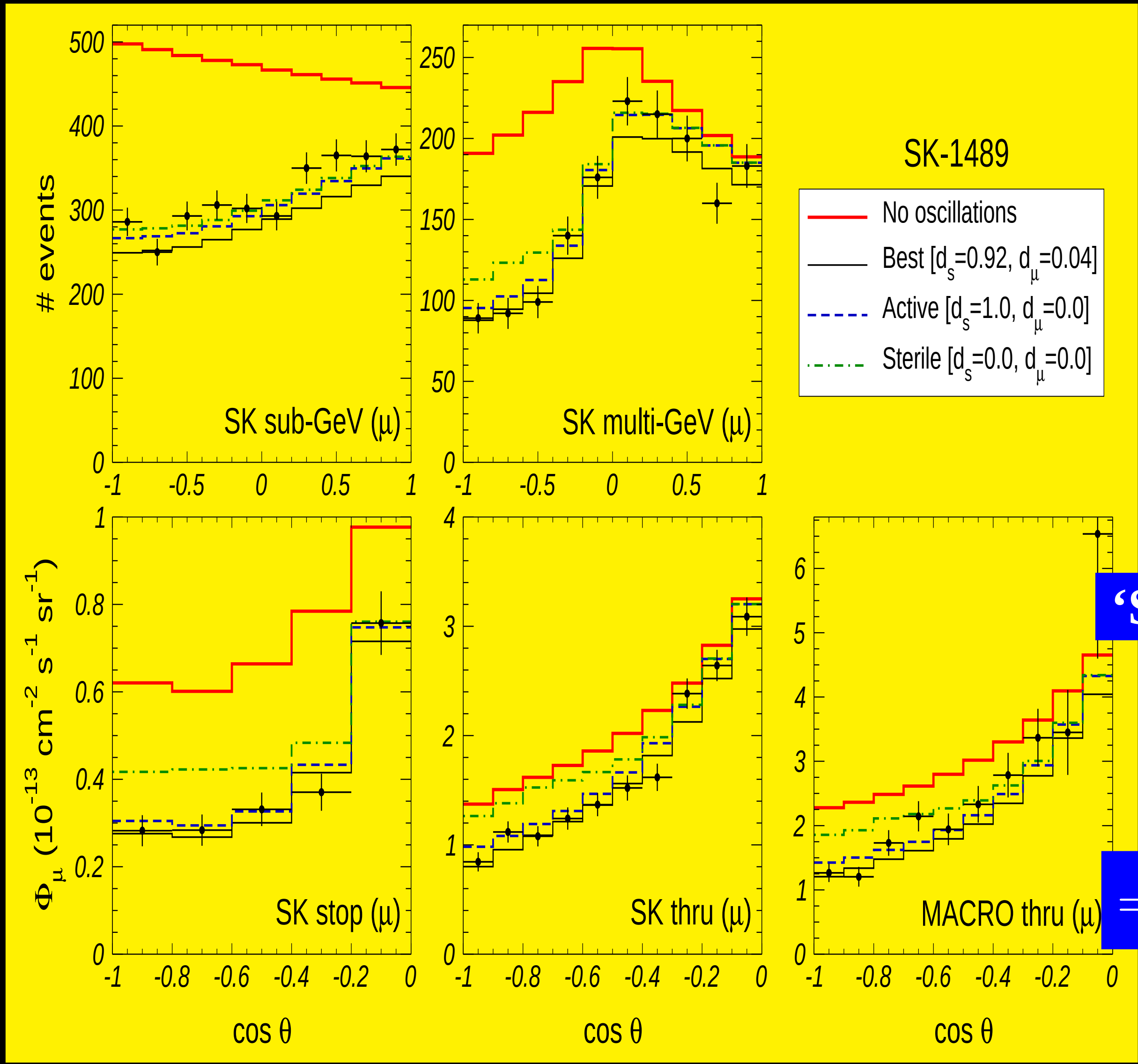
ATMOSPHERIC **SIGNAL**

deficit of earth-crossing ν_μ





Bartol, Honda

total sample

'SELF-CONTAINED'

'CONCLUSIVE'

$\Rightarrow$ flavor oscillations

Solar signal

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, ...

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

- **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, ...

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

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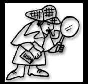
- **the 2 new phases** $n \geq 2$ **appear in L-violating processes eg** $\beta\beta_{0\nu}$
- **in general K, not U** $\Rightarrow$ **NSI**  **see hep-ph/0608101**

LEPTON MIXING MATRIX

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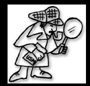
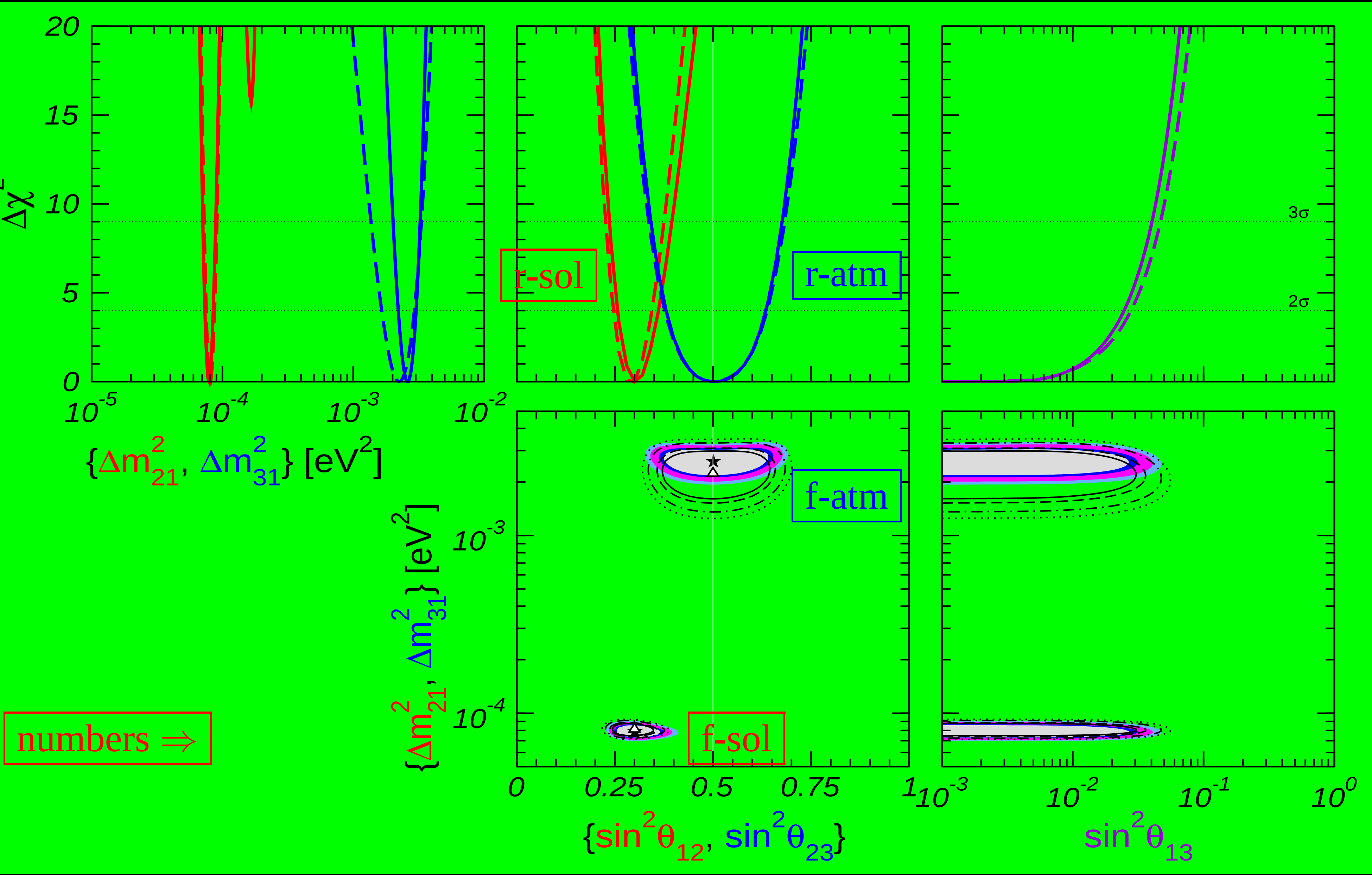
- **oscillations depend only on Dirac phase $n \geq 3$** **BHP80, Doi et al 81**
- **the 2 new phases $n \geq 2$ appear in L-violating processes eg $\beta\beta_{0\nu}$**
- **in general K, not U $\Rightarrow$ NSI**  **see hep-ph/0608101**
- **currently no expt is sensitive to CPV, so we also drop all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

5 osc parameters

CURRENT STATUS OF OSCILLATIONS

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 ?

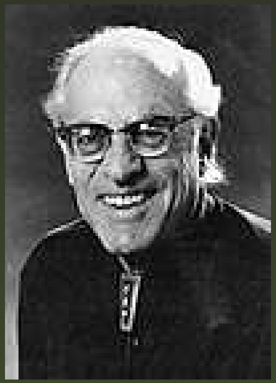
... neutrino interactions ?

ROLE OF REACTORS

neutrino discovered in reactor ..

KamLAND has solved SNP

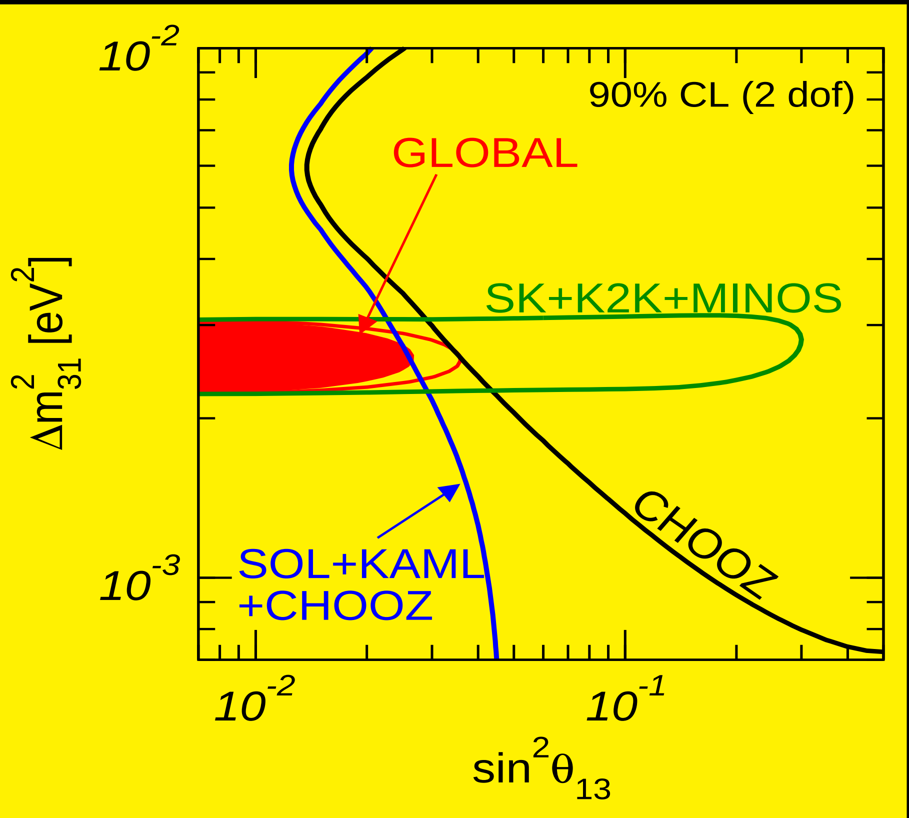
identifying oscillation as “the” soln

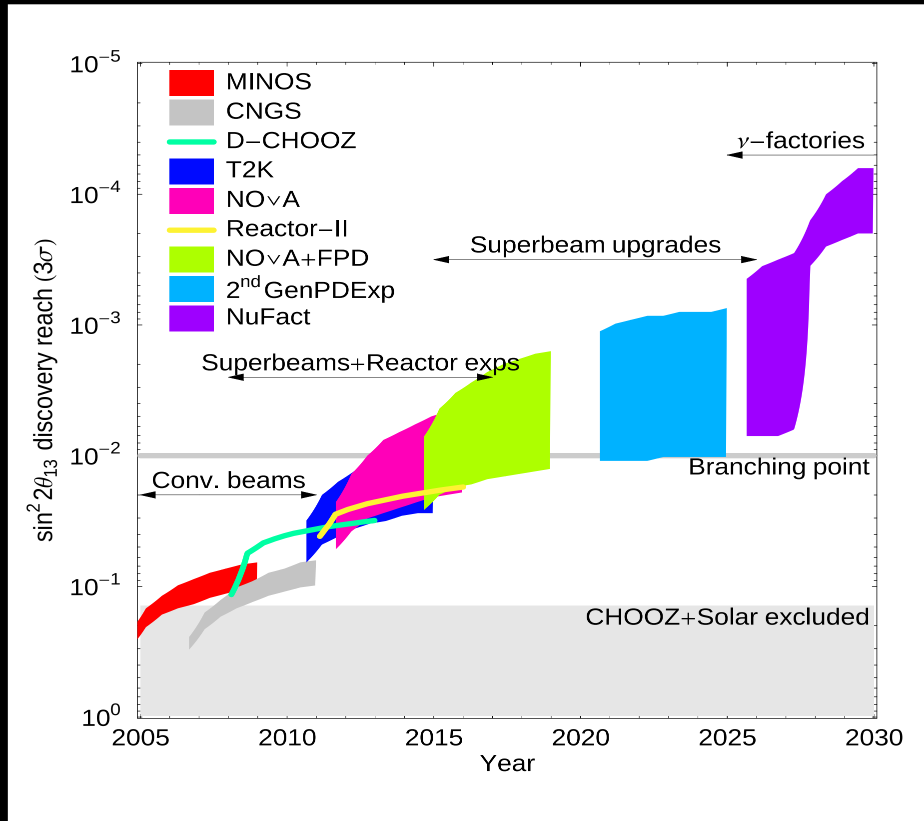


- noisy Sun robust — Burgess et al JCAP0401 (2004) 007
- SFP robust — Miranda et al PRL93 (2004) 051304 & PRD70 (2004) 113002
- NSI not quite robust yet — Miranda etal JHEP 0610:008,2006

PRESENT AND FUTURE OF θ_{13}

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





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

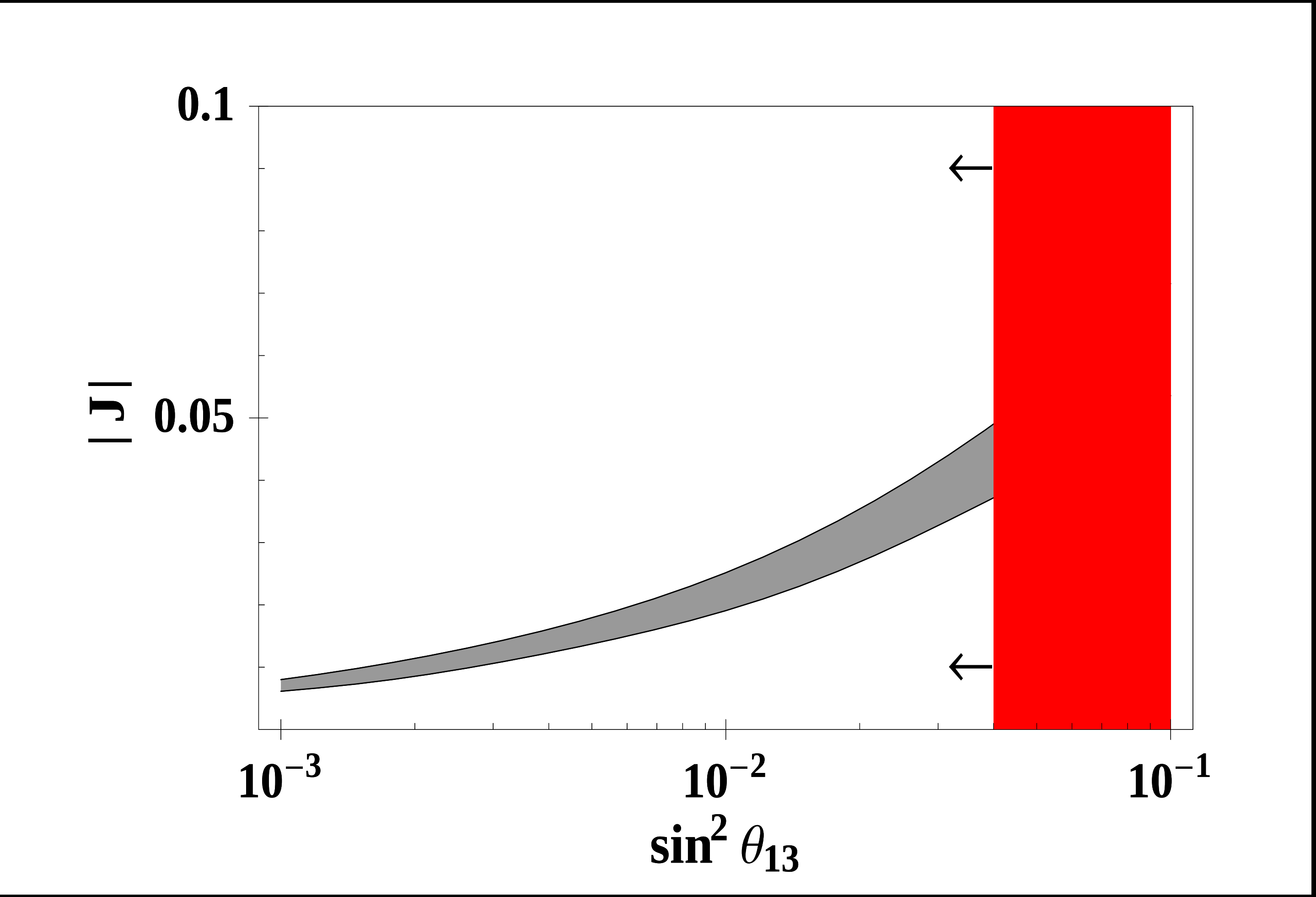
other ways? D/N solar-nu studies UNO, HK, ... Akhmedov et al JHEP05 (2004) 057

if no NSI PRL88 (2002) 101804, PRD66, 013006 (2002)

CP VIOLATION IN OSCILLATIONS

Is leptonic CP violation maximal?

Hirsch et al hep-ph/0703046



but remember ... **double price for CPV**

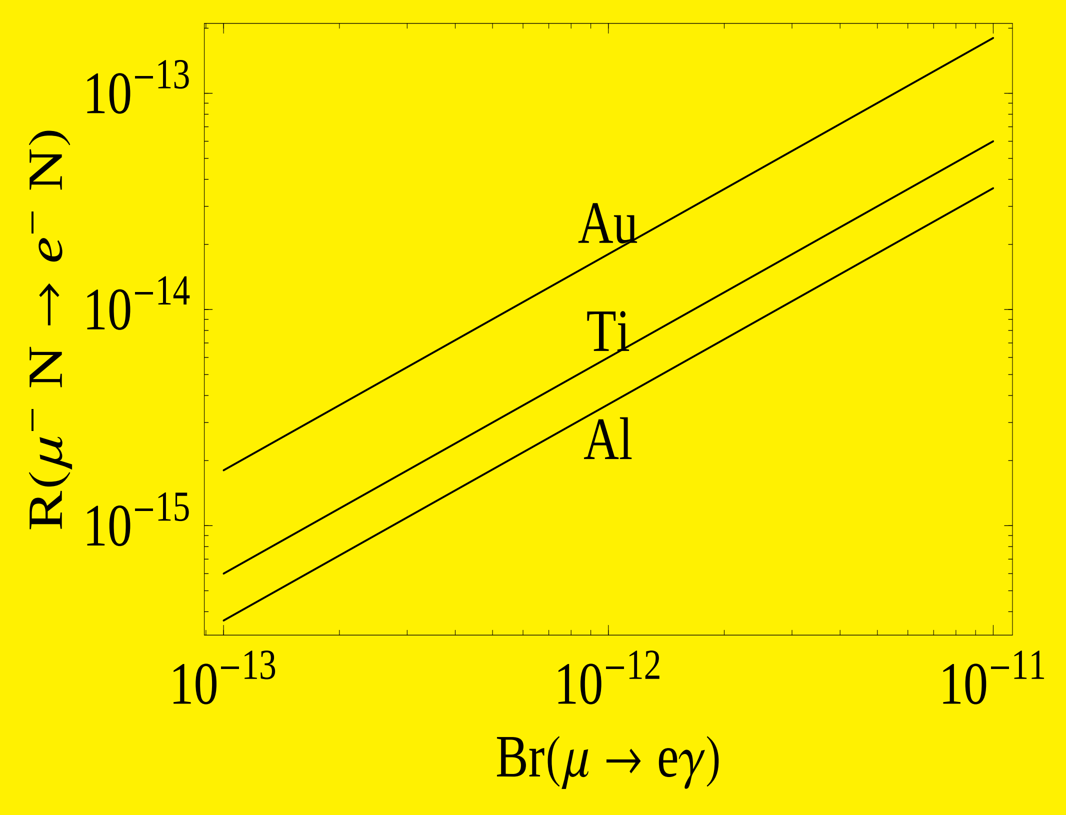
LFV BEYOND OSCILLATIONS

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

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

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 $\Rightarrow$

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

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

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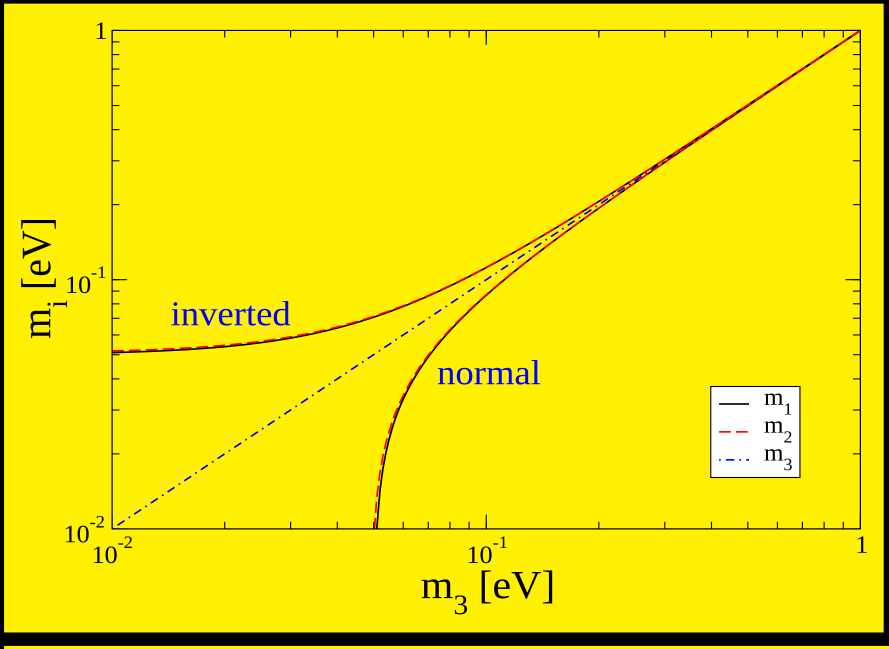
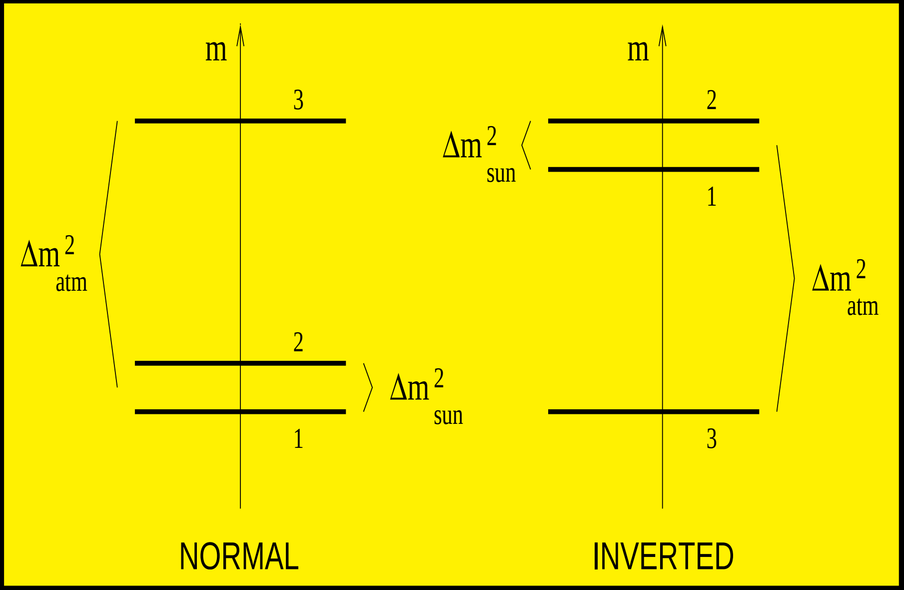
WHICH SPECTRUM?

oscil do not probe absolute masses

can not choose spectrum

need for kinematical tests !





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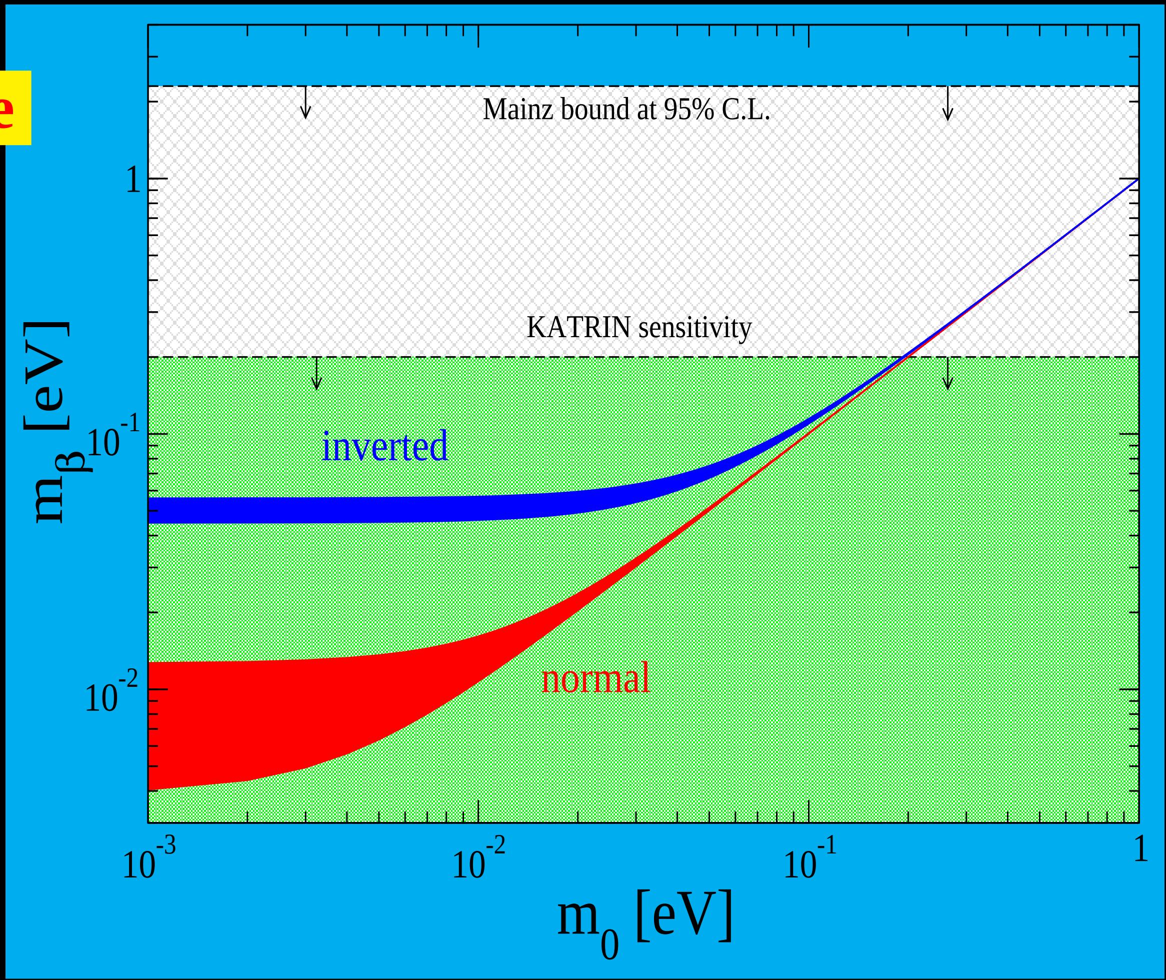
BETA DECAY

test absolute nu-mass scale

Katrin will be next high precision nu-mass expt

scales up size & source intensity

great challenge !!

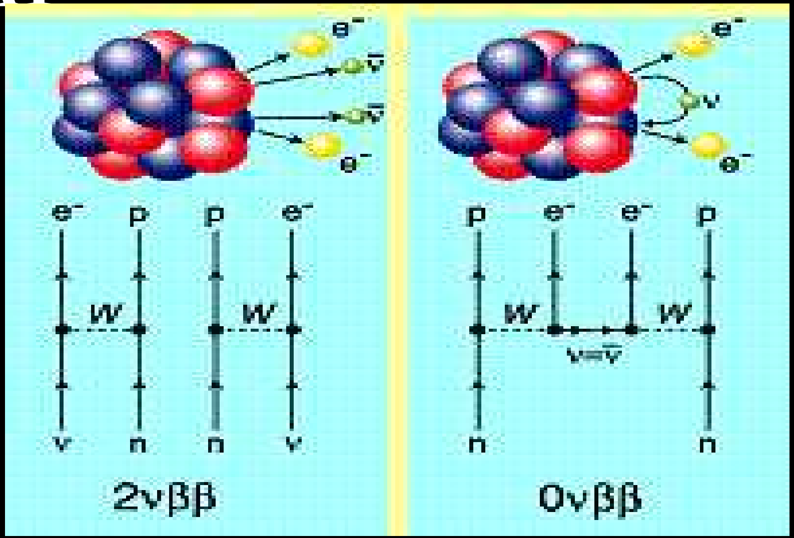


Masood et al 2006 courtesy of Tortola

0-nu DOUBLE BETA DECAY

should occur with amplitude propto

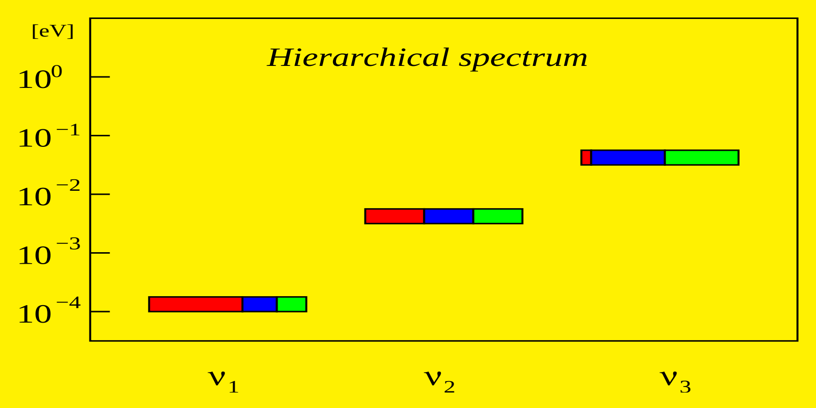
$$m_{\beta\beta} = \sum_j K_{ej}^2 m_j$$



3 masses: m_i

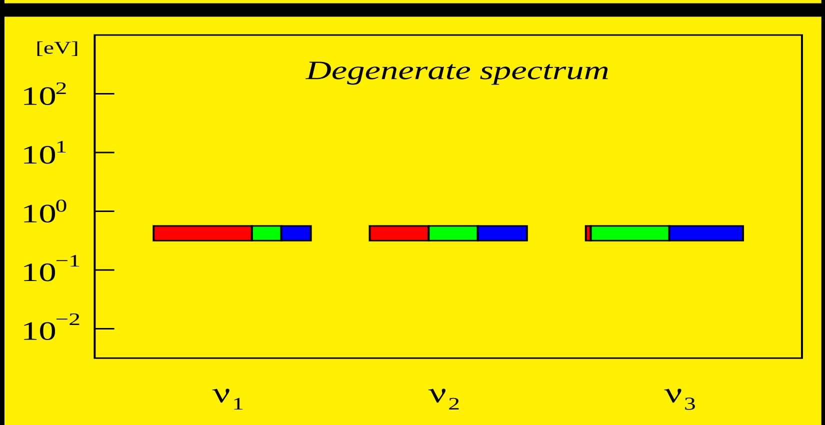
2 angles: θ_{12} and θ_{13}

2 CP phases: ϕ_{12}, ϕ_{13}



in addition to abs m-nu scale

sensitivity to Majorana phase



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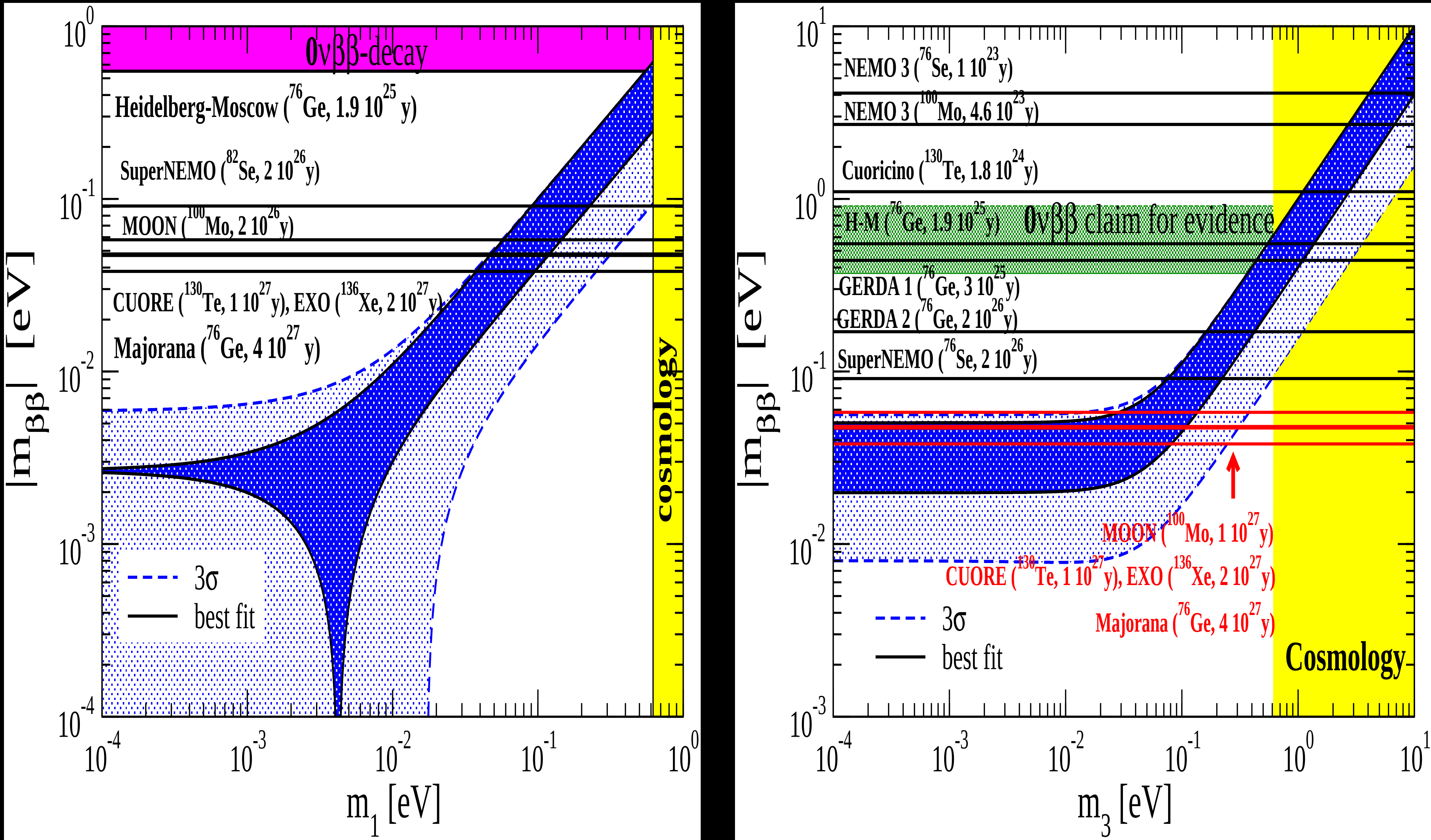
DBD



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

courtesy of Simkovic

DBD TH LOWER BOUND?

two A_4 models of nu-masses

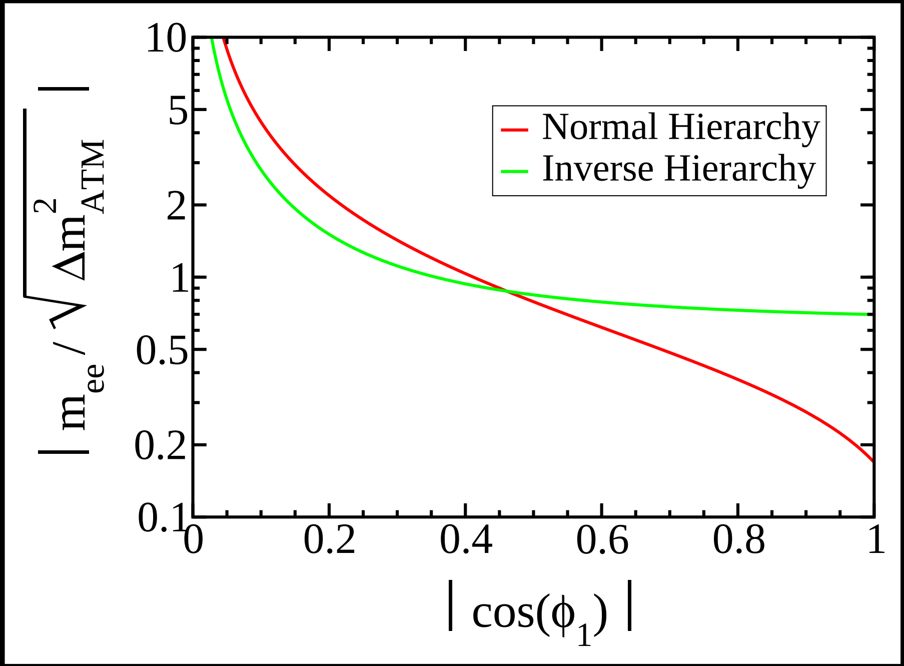
Hirsch, et al, PRD72 (2005) 091301

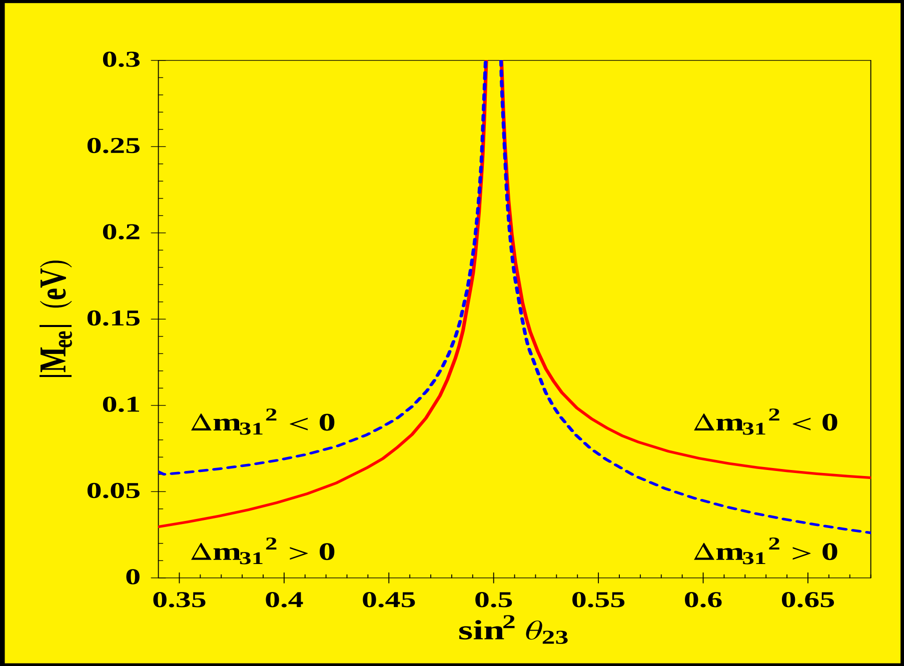
$$|\langle m_{\beta\beta}\rangle| \geq 0.17\sqrt{\Delta m^2_{\rm ATM}}$$

sensitive to Majorana phase

Hirsch et al hep-ph/0703046

even for normal hierarchy $\longrightarrow$





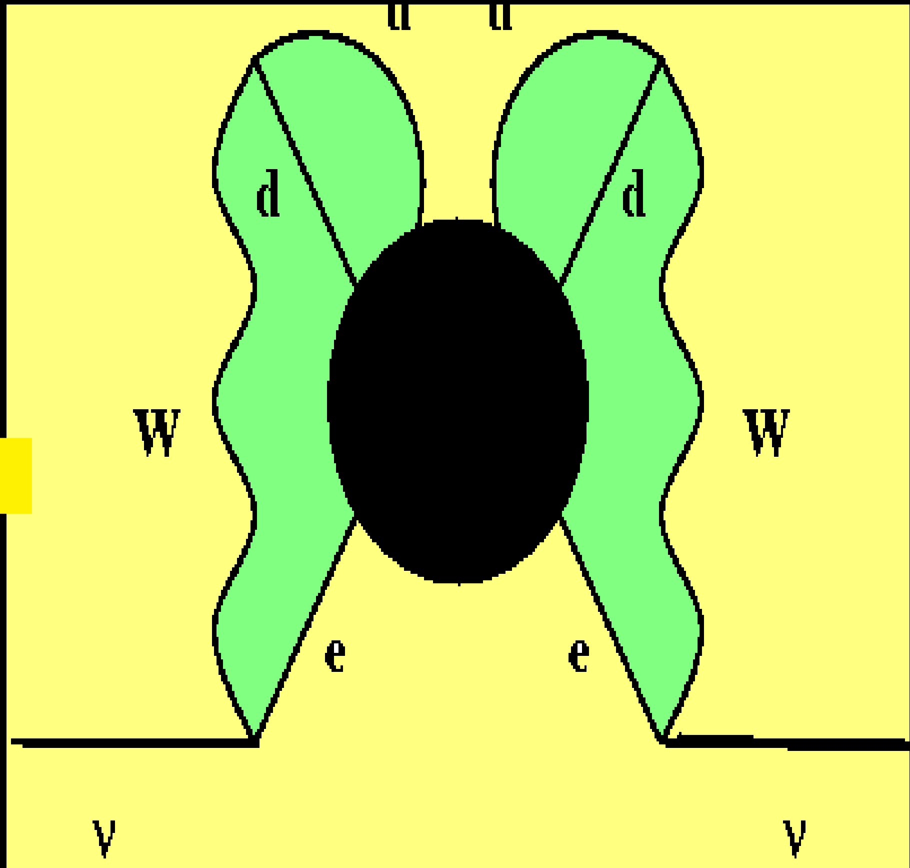
SIGNIFICANCE of 0-nu DOUBLE BETA DECAY

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

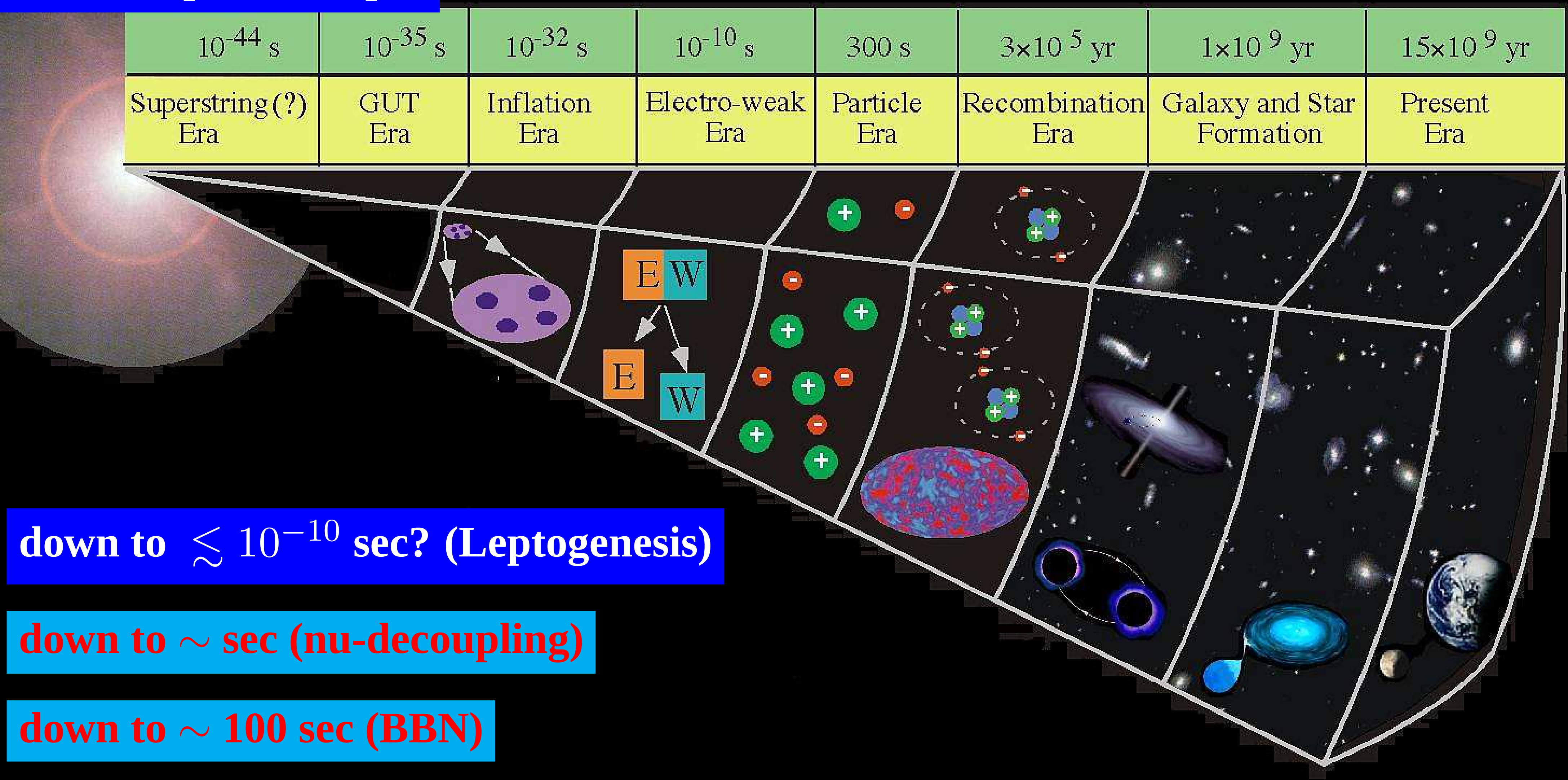


Schechter and JV, PRD25 (1982) 2951

Big Bang neutrinos as Big Bang probes

time

neutrinos probe deeper



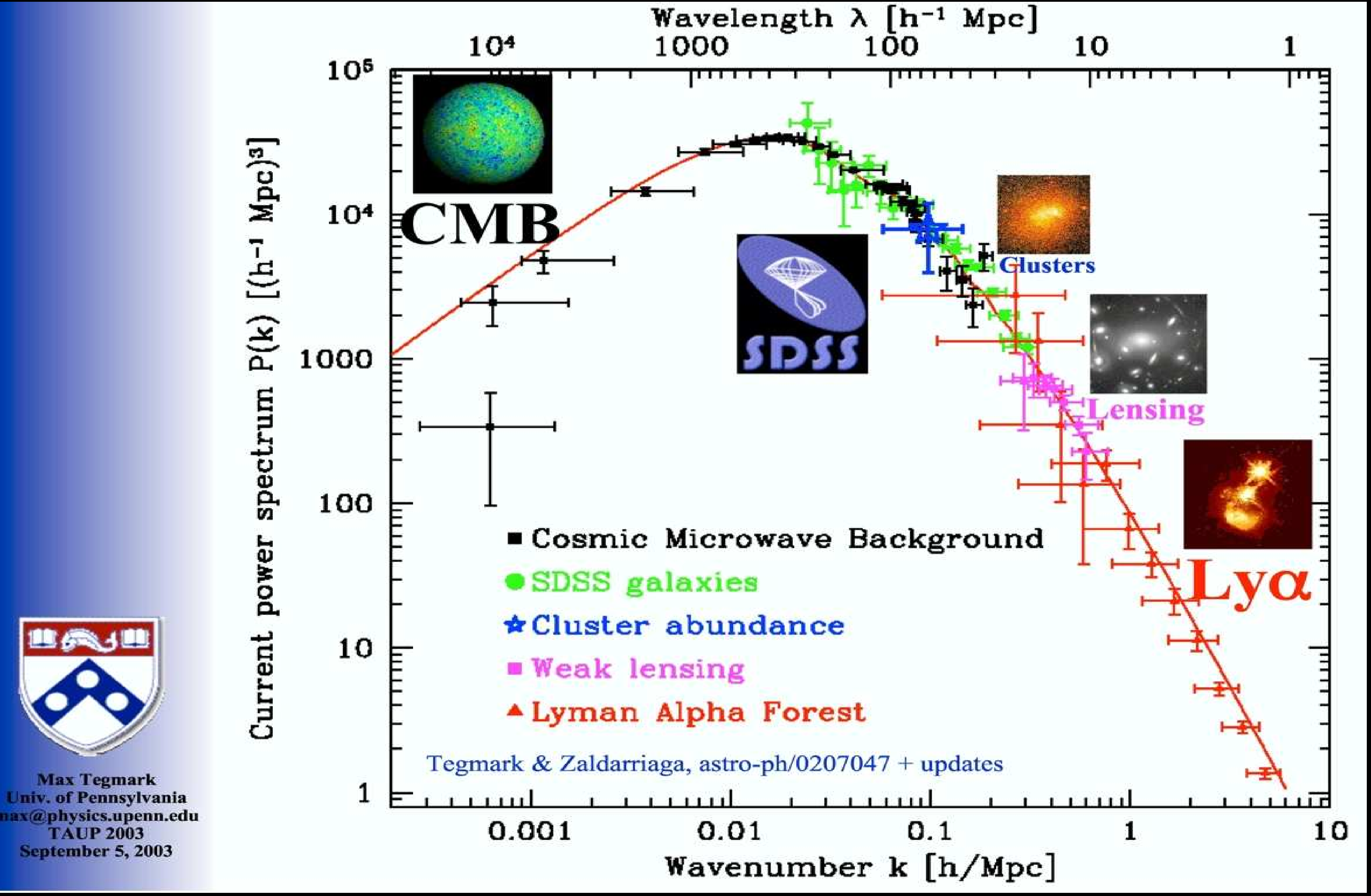
down to $\lesssim 10^{-10}$ sec? (Leptogenesis)

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

down to $\sim$ 100 sec (BBN)

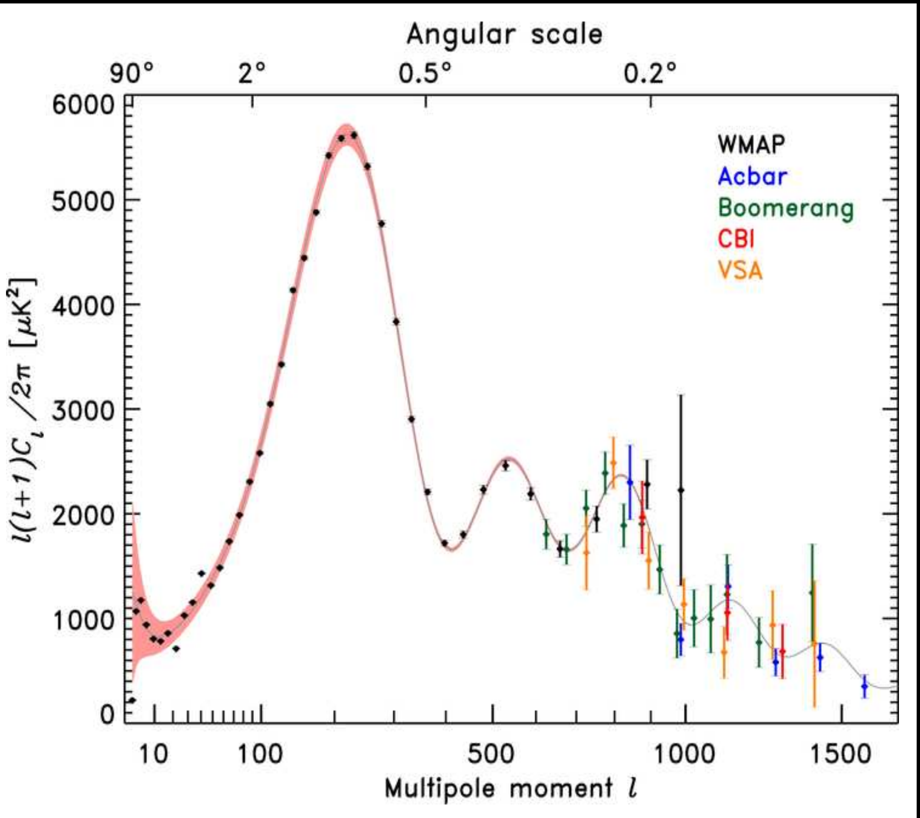
CMB & LSS

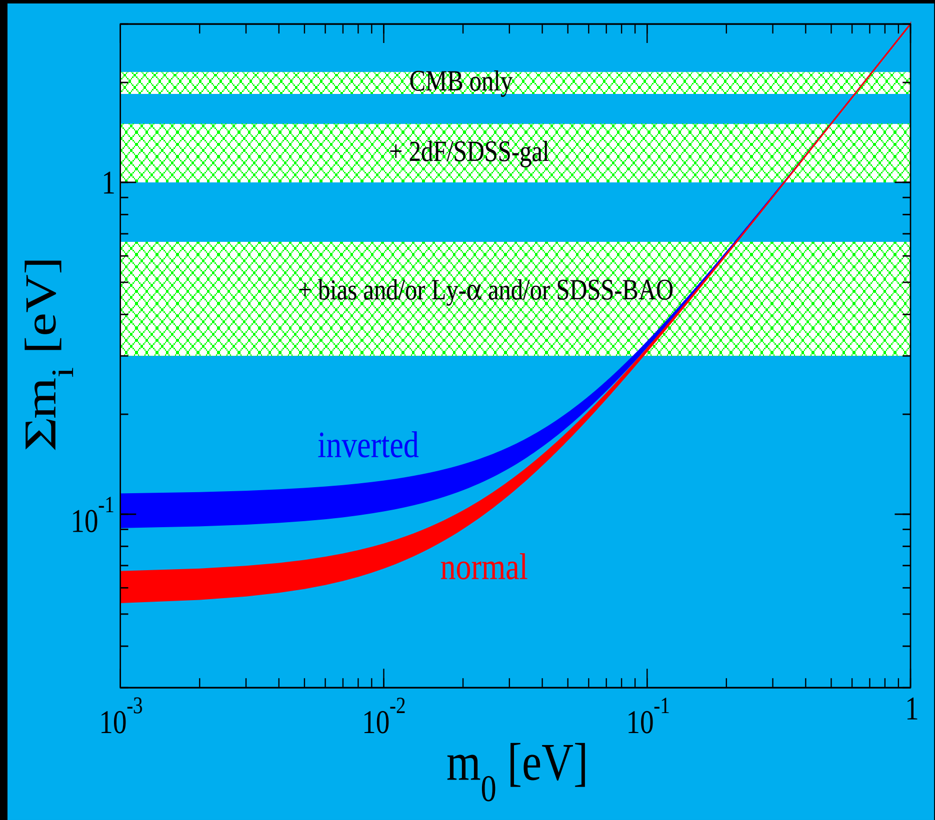
COSMOLOGY AND ABSOLUTE m-nu SCALE



⇒ **http://ahep.uv.es/**

CMB and other cosmo data





Fogli et al

Hannestad

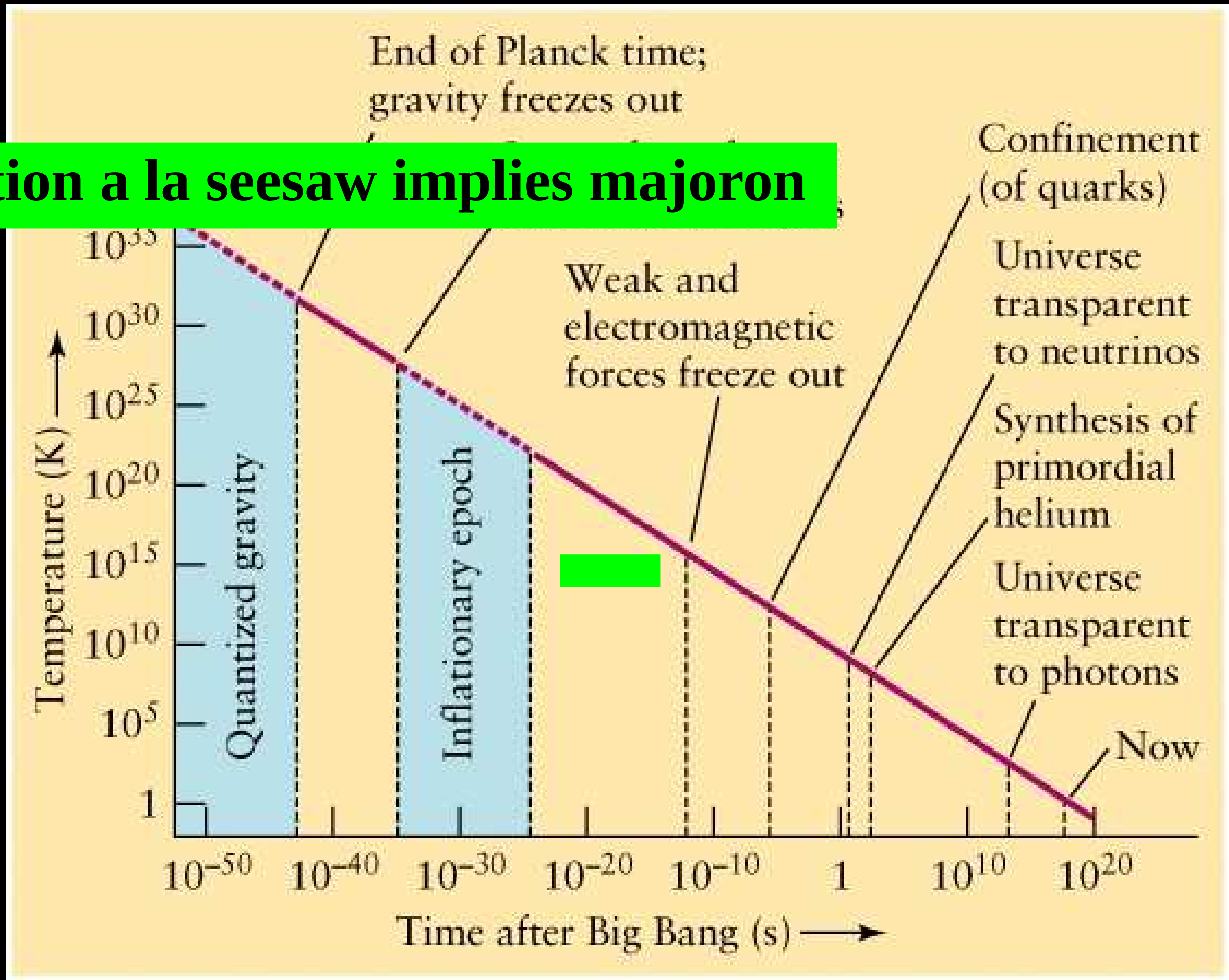
Lesgourgues & Pastor ⇒

NEUTRINOS AND DECAYING DARK MATTER

$$\Omega_J h^2 = 1.6\,\frac{m_J}{keV}\frac{n_J(t^*)}{n_\gamma(t^*)}e^{-t_0/\tau}$$

Lattanzi & Valle 0705.vvvv

spontaneous L-violation a la seesaw implies majoron



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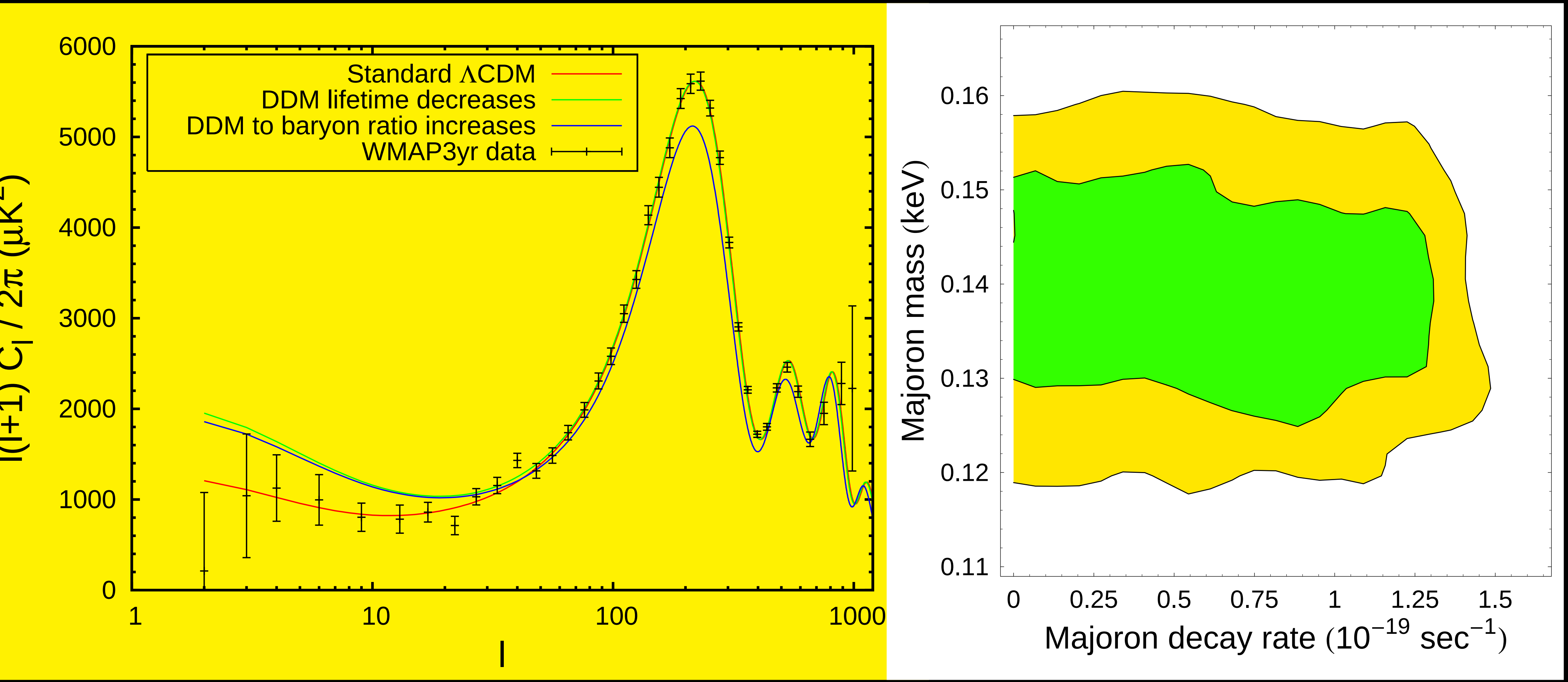
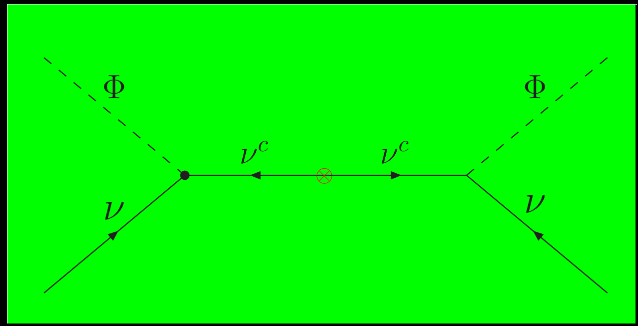
DECAYING MAJORON DARK MATTER

Lattanzi & Valle 0705.vvvv

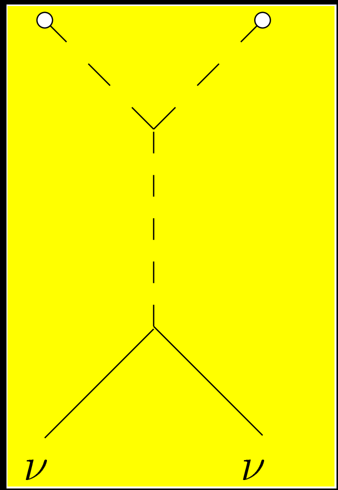


SEESAW & LEPTOGENESIS



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**

SAVING THERMAL SEESAW LEPTOGENESIS

generate cosmic baryon/photon ratio from out-of-equilibrium decay of heavy singlets Fukugita, Yanagida 86

simplest (type-I) supersymmetric seesaw requires lightest singlet $\gtrsim 10^9$ GeV

gravitino crisis

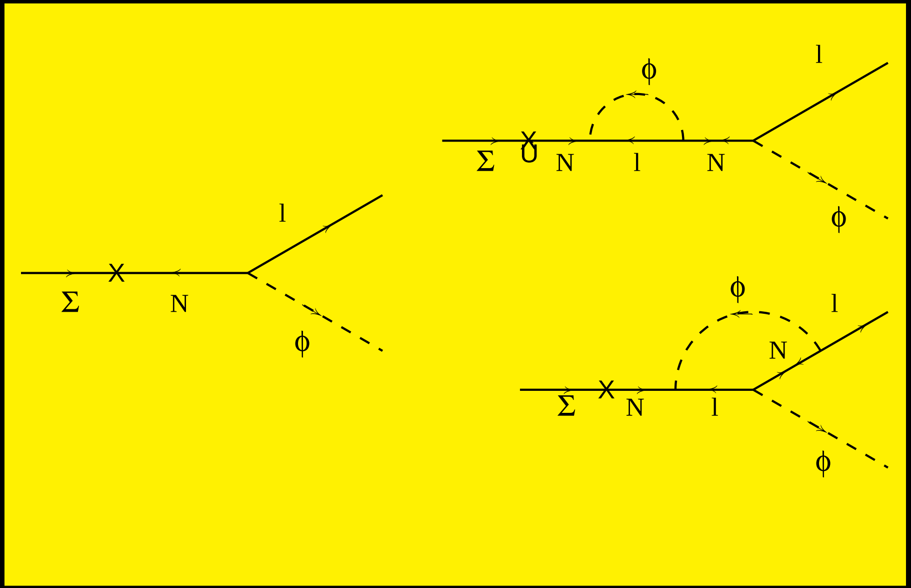
two ways to achieve thermal LG:

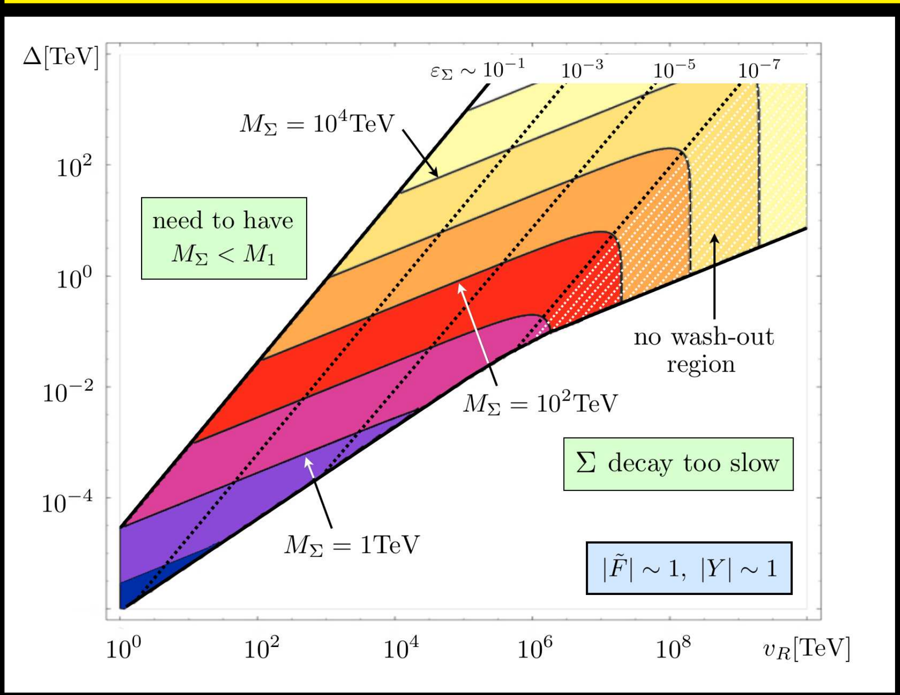
EXTENDED SEESAW

Hirsch et al PRD75 (2007) 011701

Small R-p violation $\lambda \hat{N} \hat{H}_u \hat{H}_d$

Farzan & Valle PRL (2006) 011601

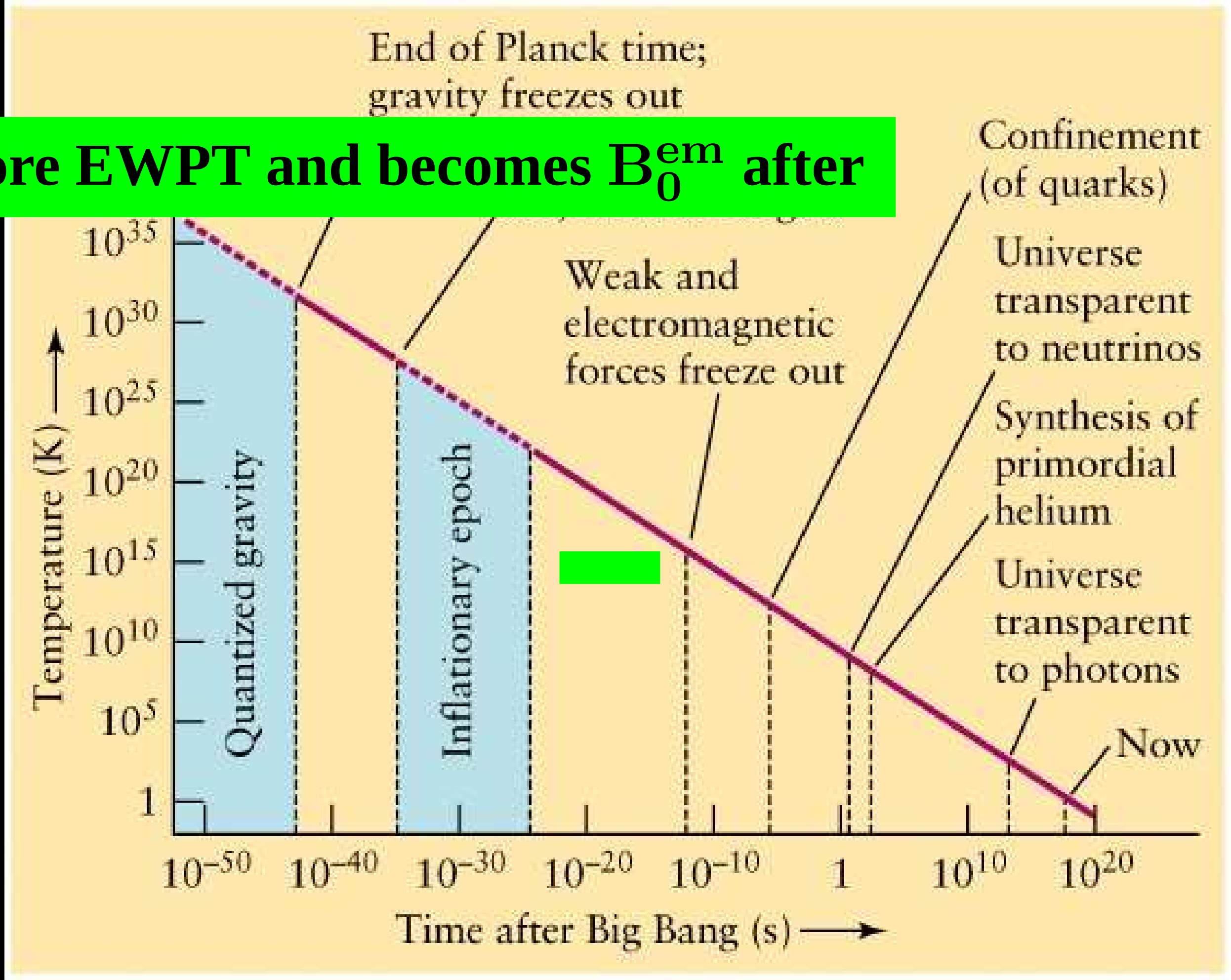




NEUTRINOS AND SEED MAGNETIC FIELDS

$$B_Y(x) = B_0^Y \exp\left[10^2 \int_x^{x_0} \frac{dx'}{x'^2}\left(\frac{\xi_\nu(x')}{0.001}\right)^2\right]$$

Semikoz & Valle 0704.3978



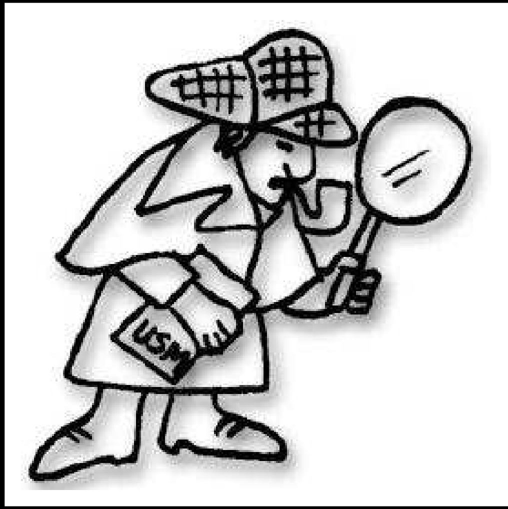
B_0^Y grows before EWPT and becomes B_0^{em} after

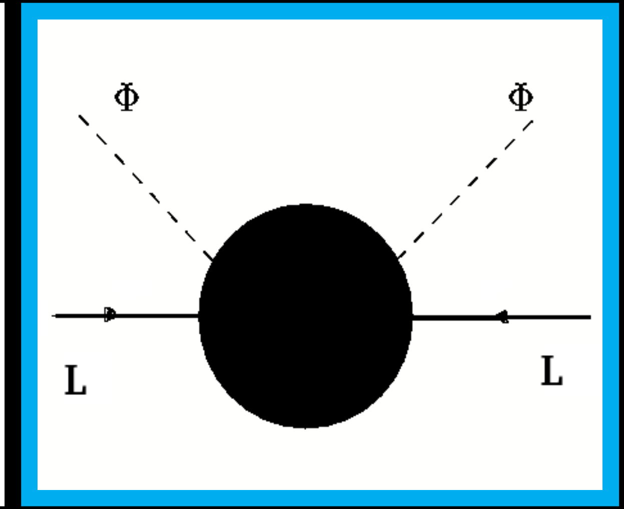
NEUTRINOS AS MESSENGERS

neutrinos ideal to monitor the Universe, the interior of the sun, stars, etc

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

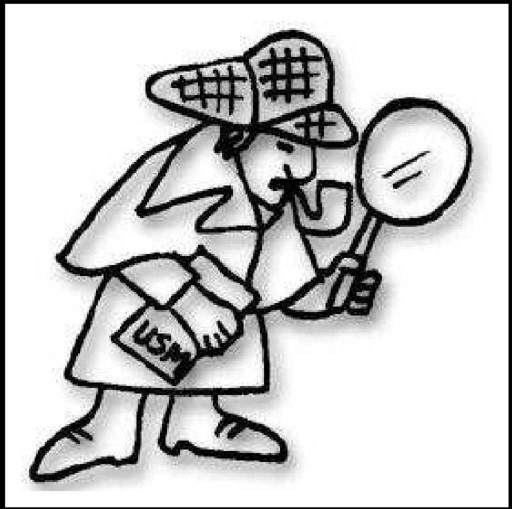
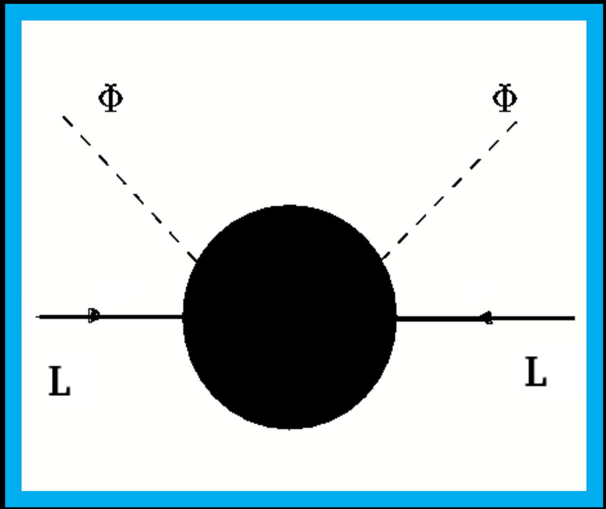
NEUTRINOS AS “THEORY” MESSENGER





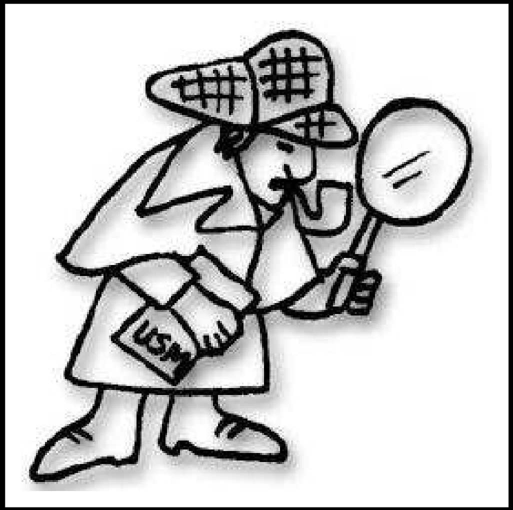
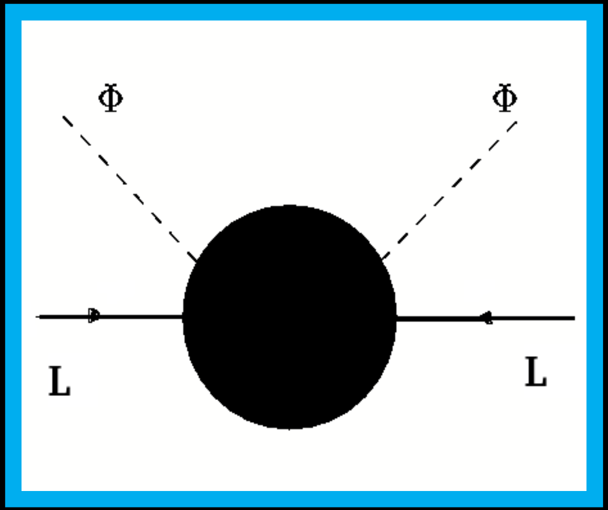
Weinberg PRD22 (1980) 1694

NEUTRINOS AS "THEORY" MESSENGER

- 


Weinberg PRD22 (1980) 1694
- which scale ⇒

NEUTRINOS AS "THEORY" MESSENGER

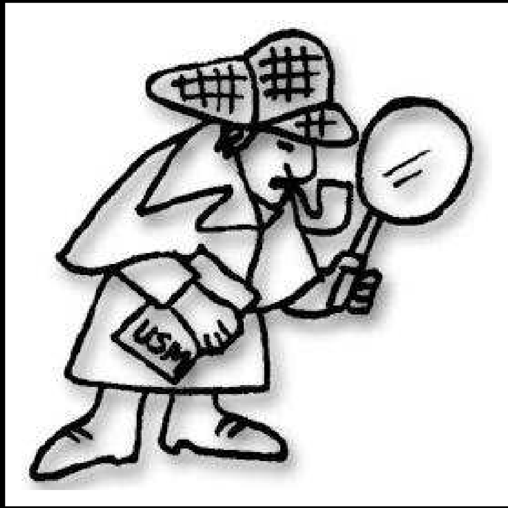
-  

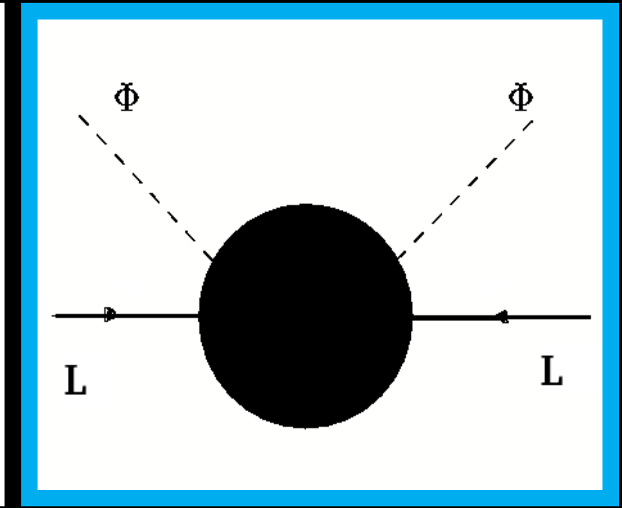
Weinberg PRD22 (1980) 1694

- which scale ⇒

- which flavour structure

NEUTRINOS AS “THEORY” MESSENGER





Weinberg PRD22 (1980) 1694

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

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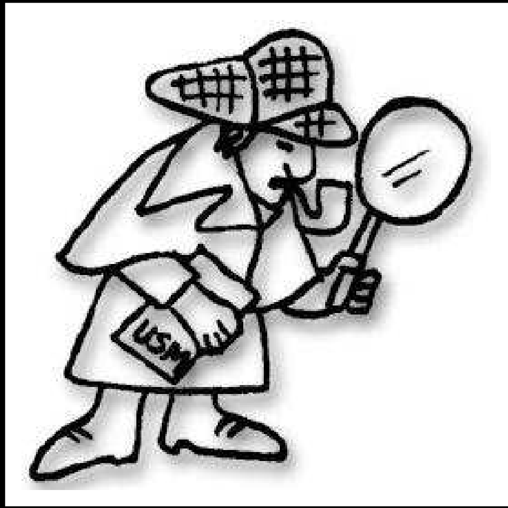
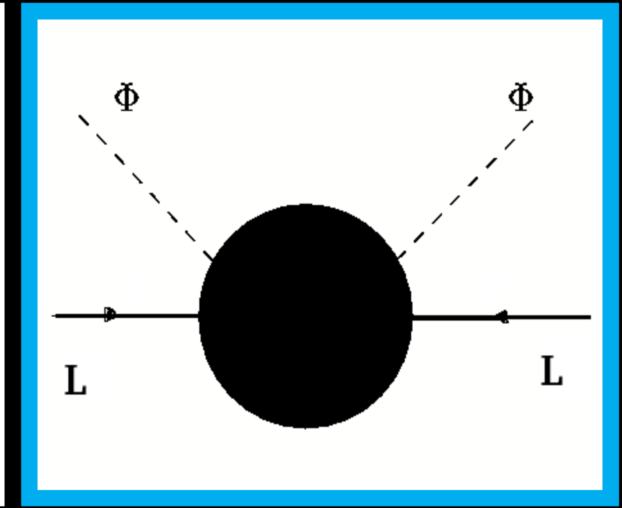
- 


Weinberg PRD22 (1980) 1694

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

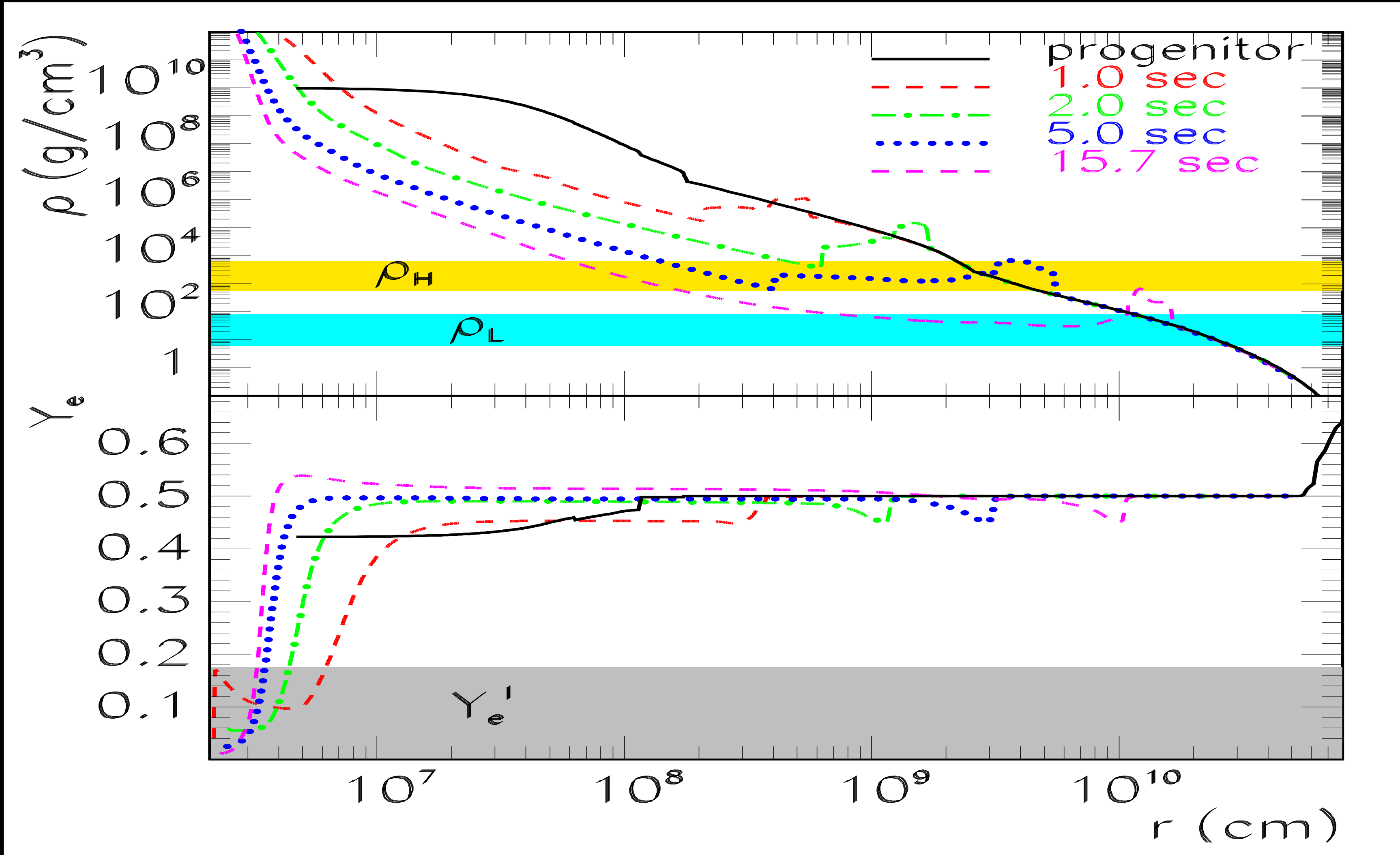
- **things should be made as simple as possible, but not simpler**
Albert Einstein

FIN

BACKUP SLIDES

from here on there is no logical order among slides

NEUTRINOS AS SN-PROBE



outer conversions due to oscillations atm sol

NSI-induced inner resonance

Valle PLB199 (1987) 432, Nunokawa et al 96

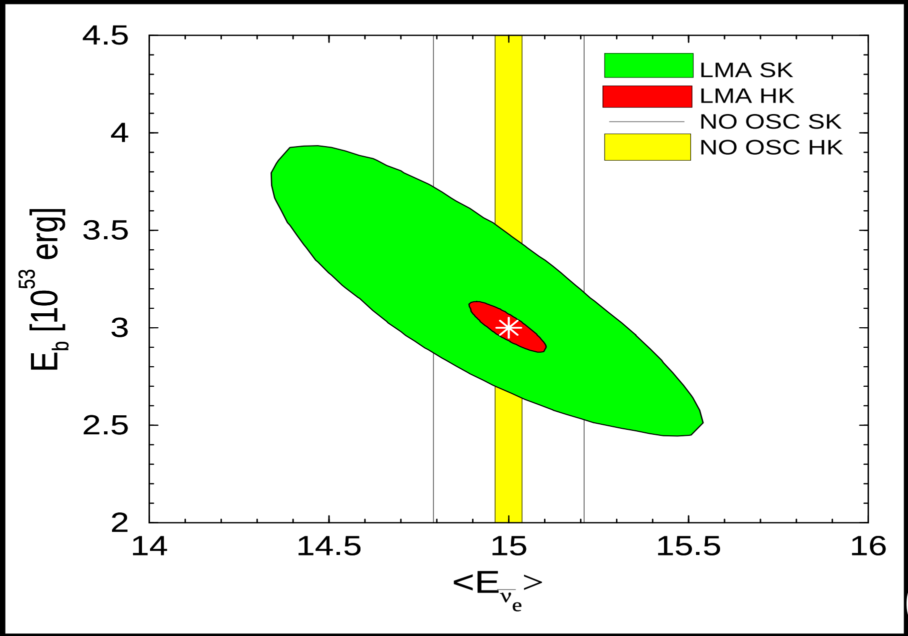
http://ahep.uv.es/

NEUTRINOS AS SN-PROBE-osc

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)

NEUTRINOS AS SN-PROBE-nsi

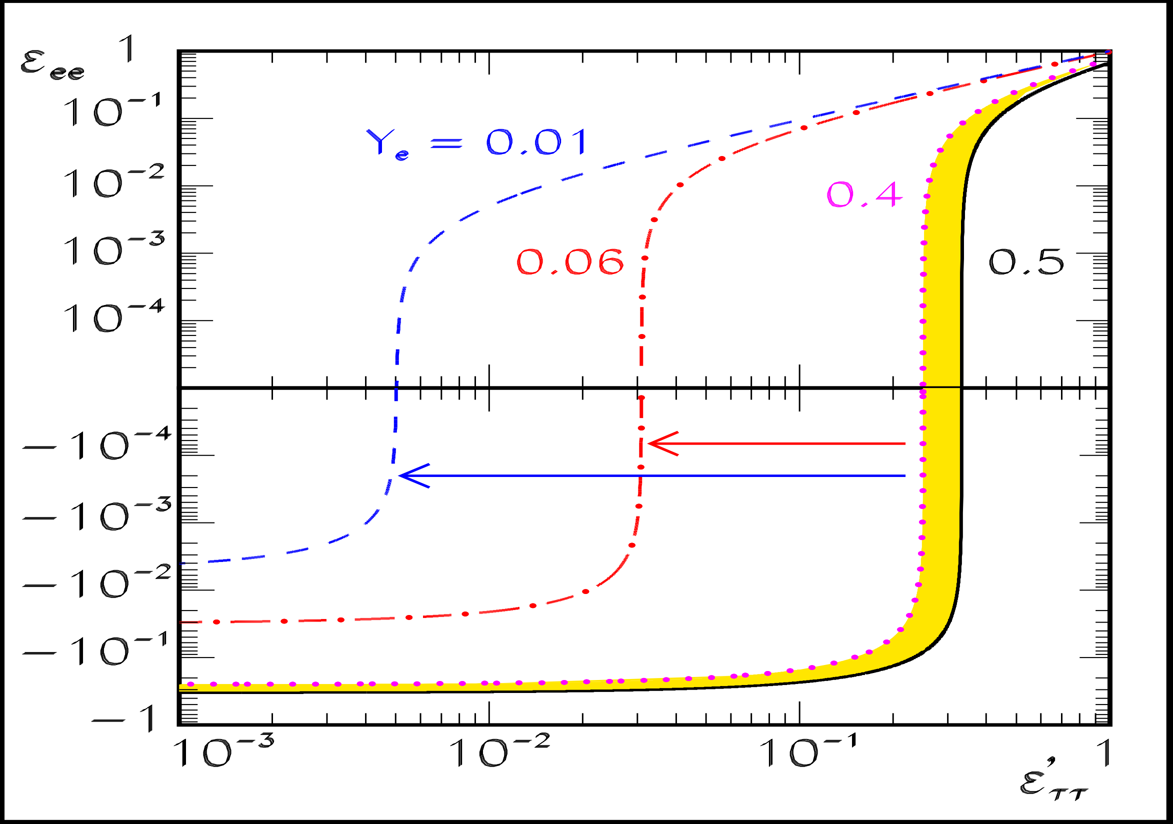
probing non-standard neutrino interactions with supernova neutrinos

Esteban-Pretel,Tomas, Valle arXiv:0704.0032

simulate nu-signal from 10 kpc galactic SN

new effects in nu-conversions

in neutron-rich regime

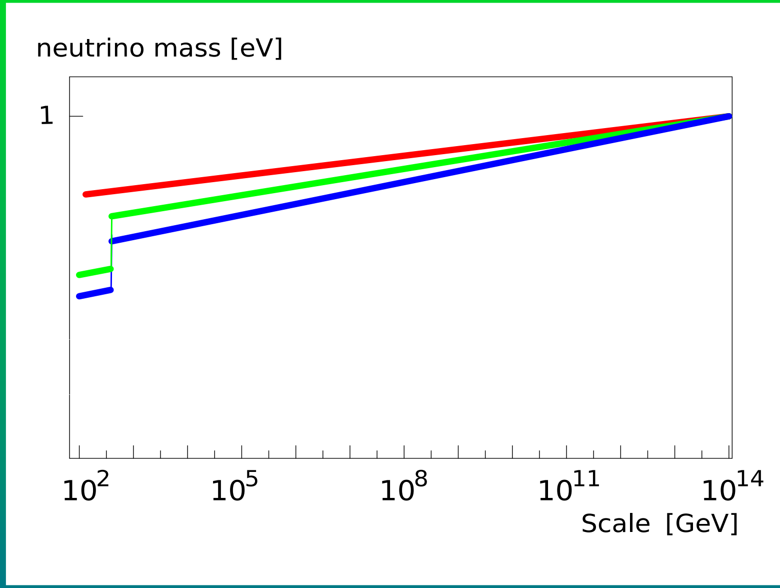


a future galactic nu-signal will give us good info on nu-properties

PREDICTING NU-MASSES & MIXINGS

neutrino unification "top-down"

Chankowski et al PRL86 (2001) 3488



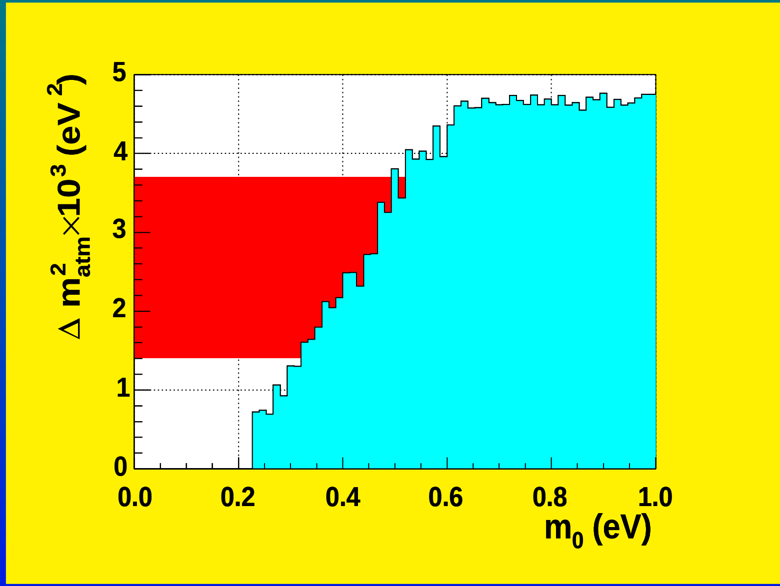
due to A4 Babu, Ma & JV, PLB552 (2003) 207
Hirsch et al, PRD69 (2004) 093006

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

[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

tri-bimaximal mixing at high energies

Harrison, Perkins & Scott

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

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

mainly $\theta_{\rm SOL}$ modified at low energies by radiative corrections

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

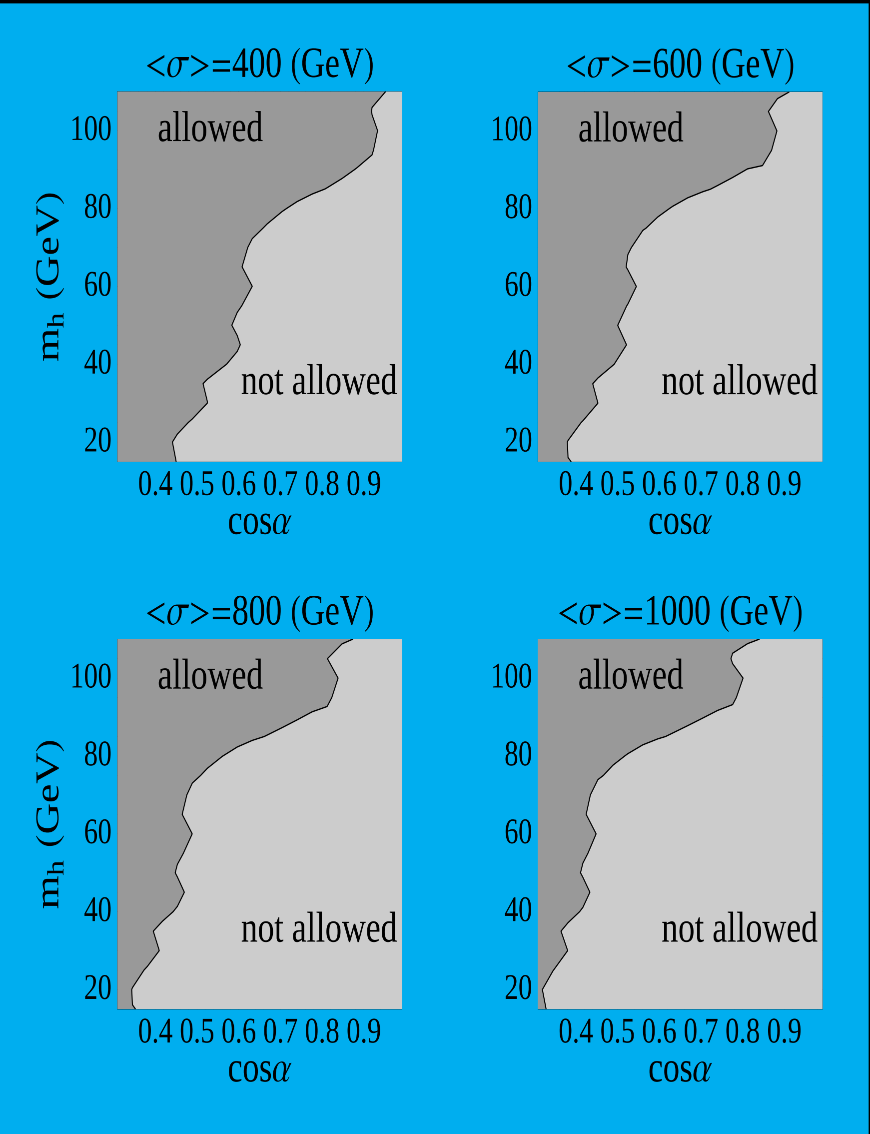
related work by

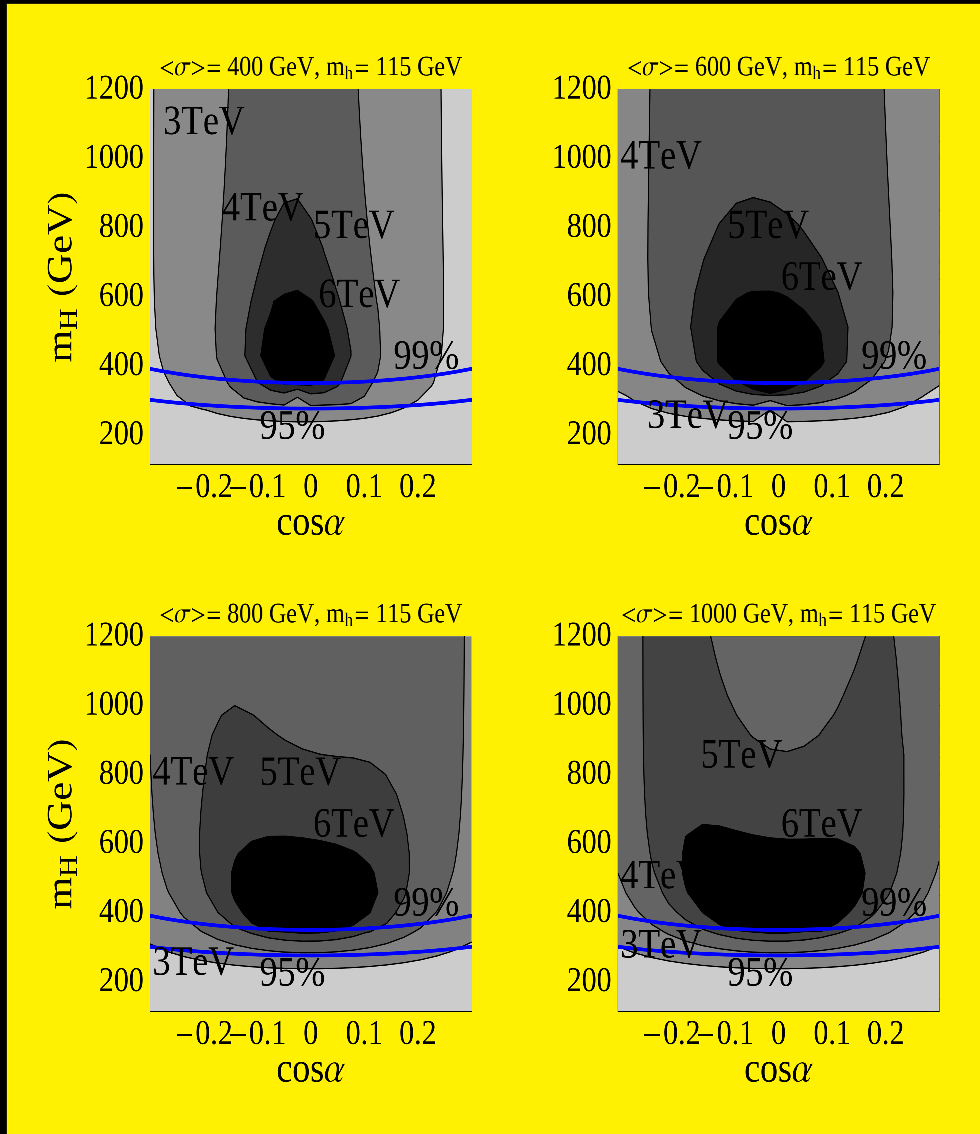
also Altarelli & Feruglio 06, He & Zee 06, Z Z Xing, ...

NU-MASSES AND EW SYMMETRY BREAKING

Joshipura & JV, NPB397 (1993) 105

Bazzochi & JV hep-ph/0609093

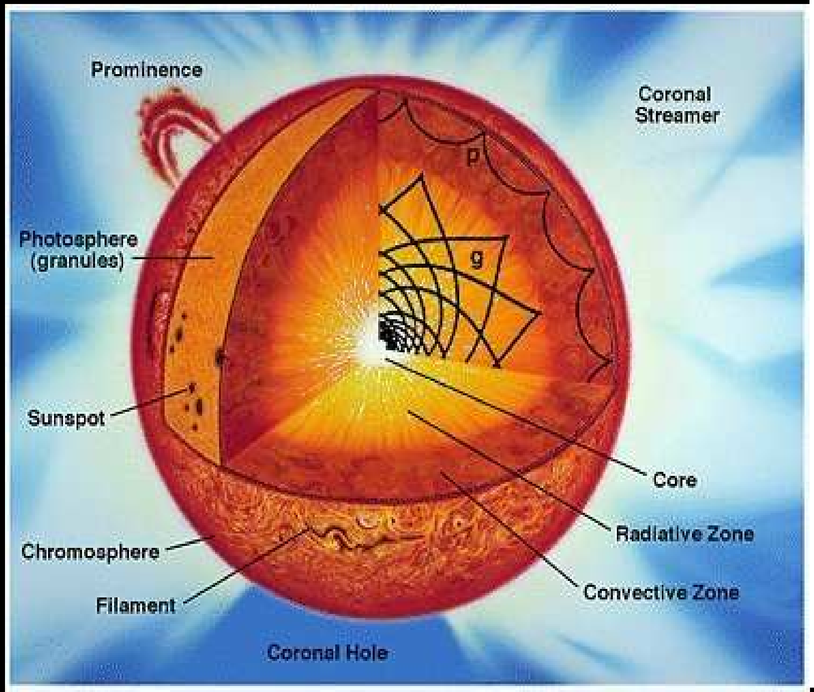


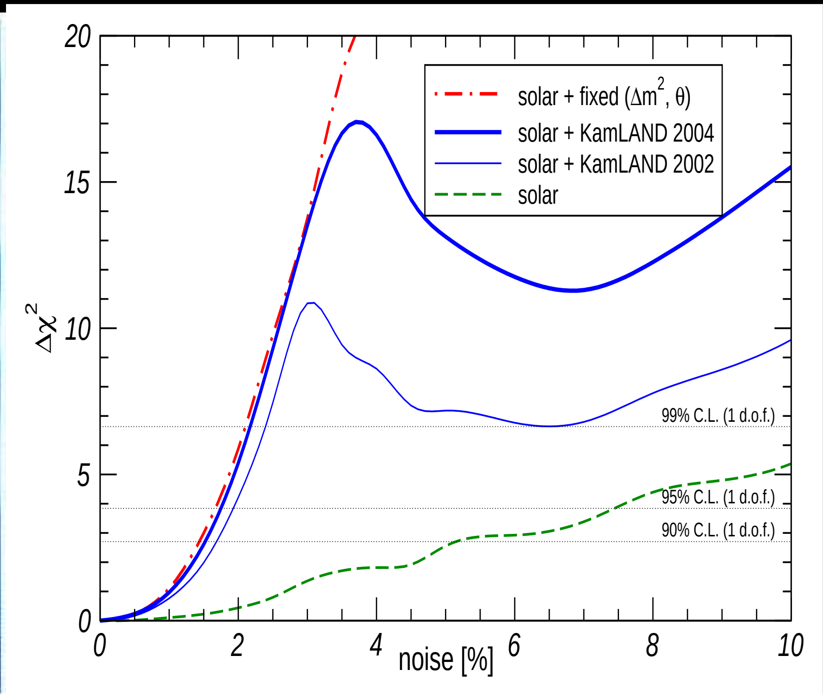


nu-OSCILLATIONS AS DEEP SOLAR PROBE

- 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

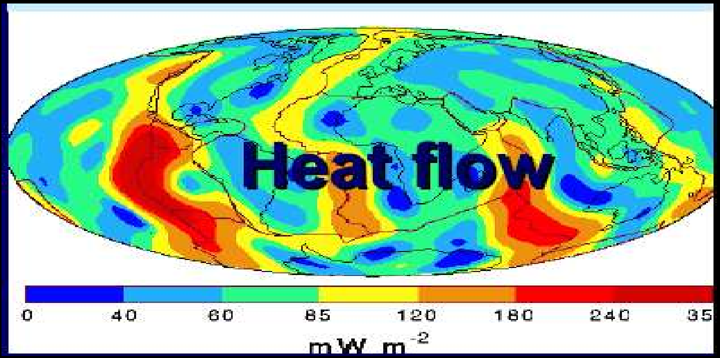
- neutrinos from natural radioactive decays in the Earth's interior give a 3d map

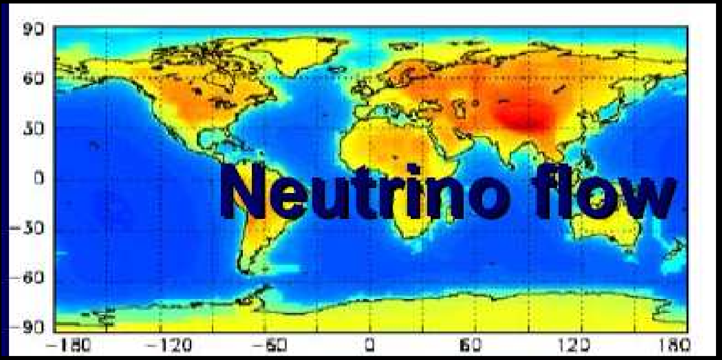
Fiorentini et al ⇐

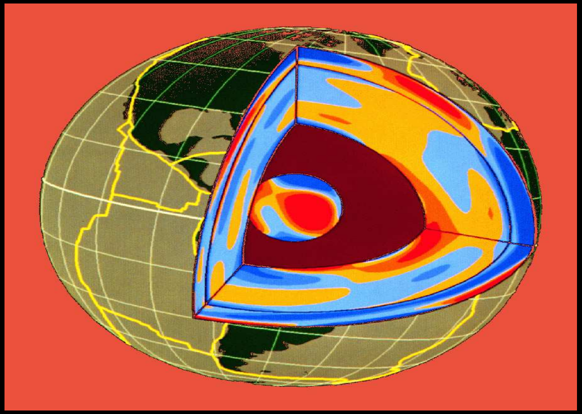
- also, Earth matter effect on solar and supernova neutrino oscillations inside the Earth enable in principle reconstruct the Earth's electron number density profile.

geotomography with solar & 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

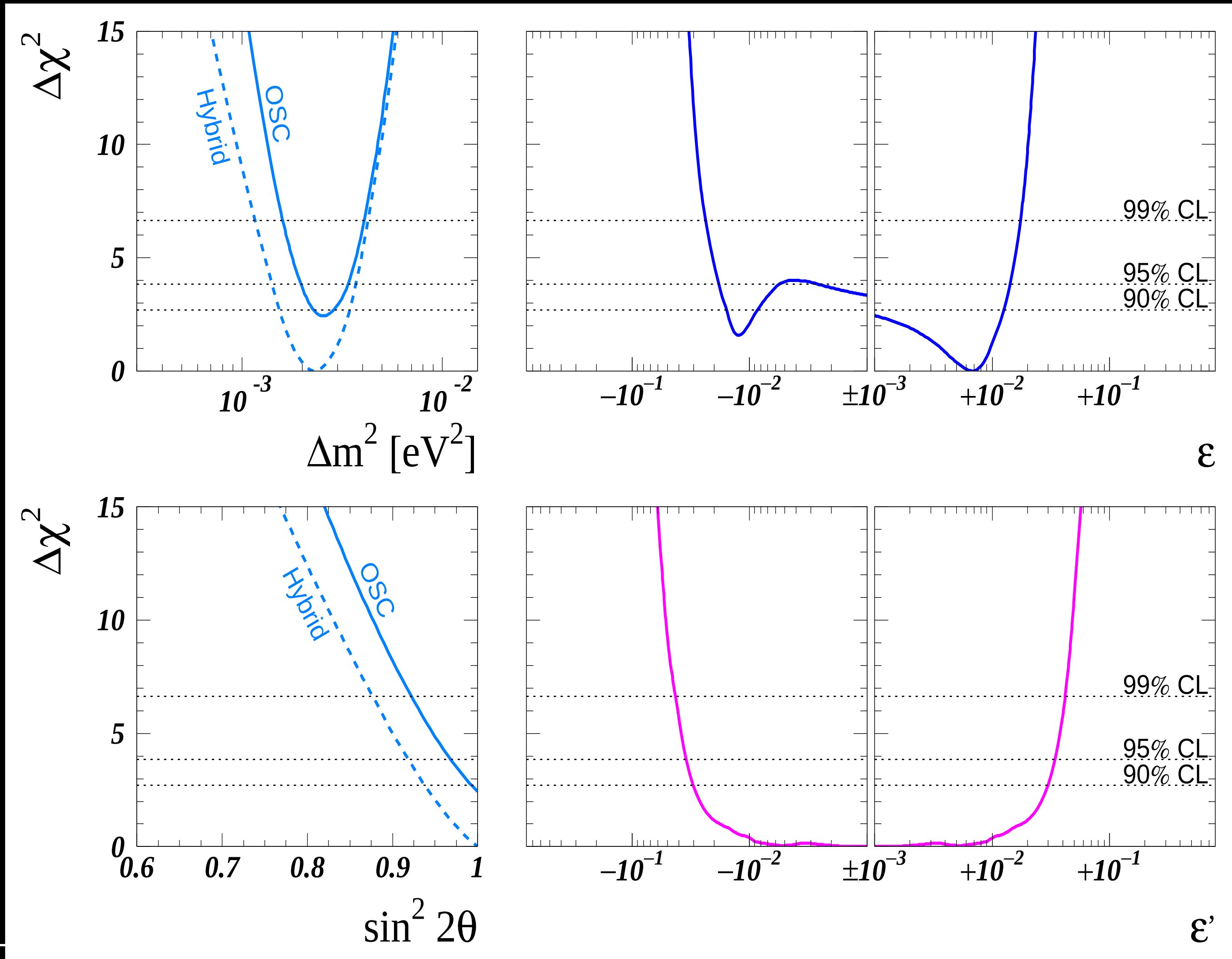
Table I: **THREE–NEUTRINO OSCILLATION PARAMETERS-2006**. Best-fit values, 2σ, 3σ, and 4σ intervals (1 d.o.f.) for the 3-nu neutrino oscillation parameters from global data from solar, atmospheric, reactor (KamLAND and CHOOZ) and accelerator (K2K and MINOS) experiments.

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

ROBUSTNESS OF ATM-N 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

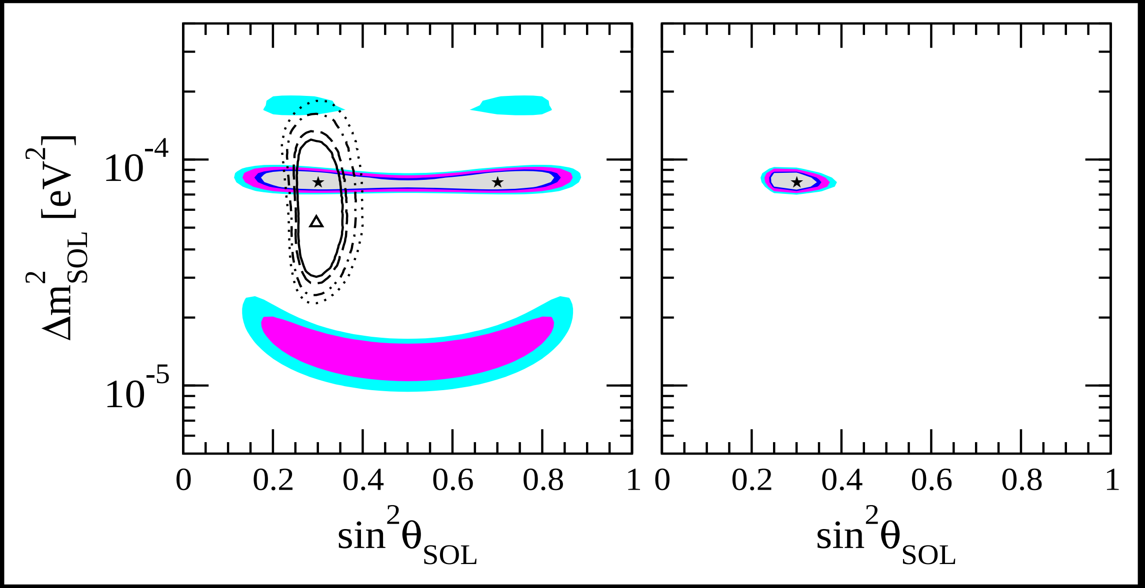
FRAGILITY OF SOLAR-NU?

wrt NSI

Miranda etal, hep-ph/0406280

JHEP 2006

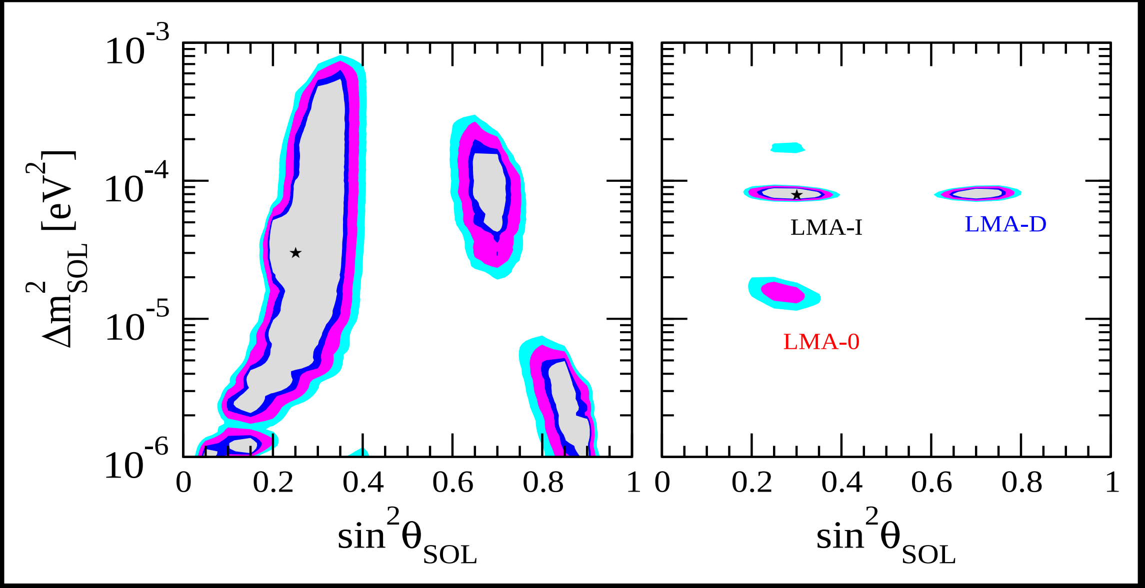
Glbview



degenerate dark-side soln, unresolved by KamLAND

NSI

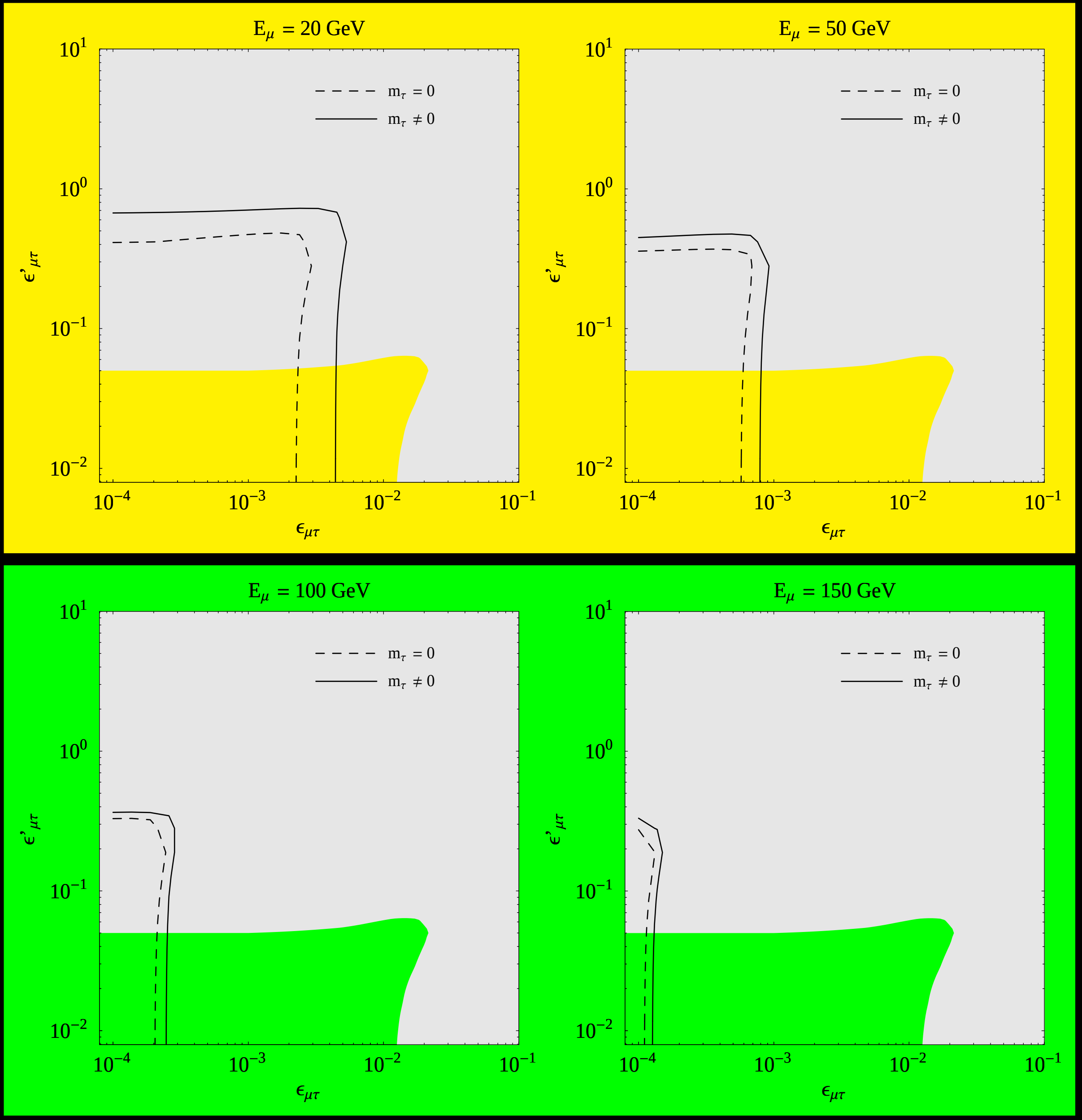
resolve



FC-NSI-tests at generic NuFact

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

improved FC test



Huber & JV PLB523 (2001) 151

FCI-oscillation CONFUSION THEOREM

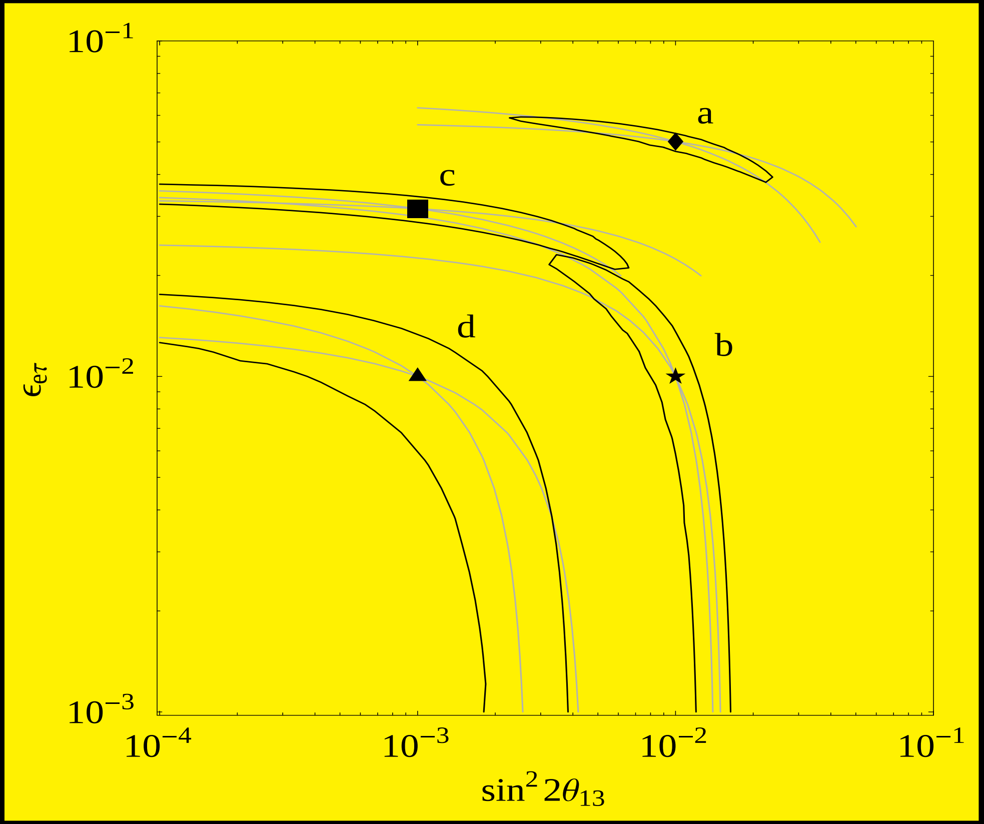
- a neutrino factory is less sensitive to θ_{13} because non-standard neutrino interactions are confused with oscillations

Huber et al, PRL88 (2002) 101804

& PRD66 (2002) 013006

near-site programme essential

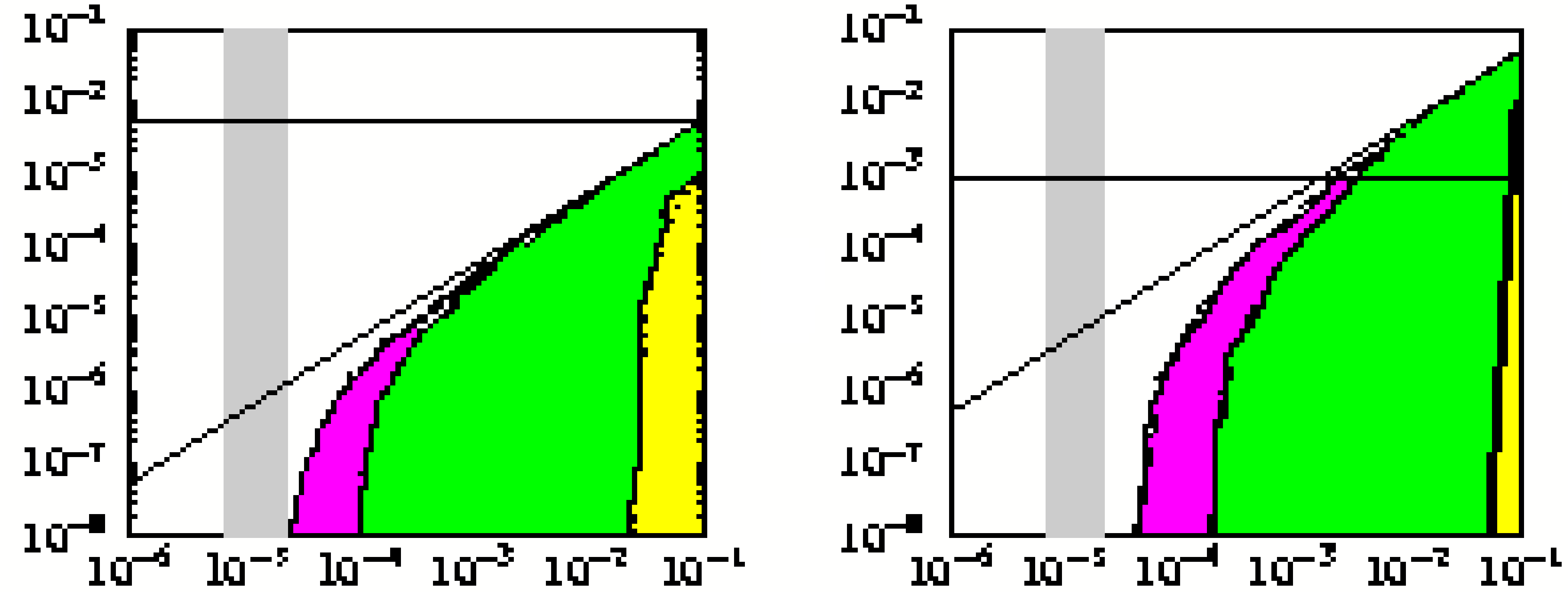
2×10^{20} mu/yr/polarity $\times$ 5 yr, 40 kt magn iron calorim, 10% muon E-resoln above 4 GeV



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

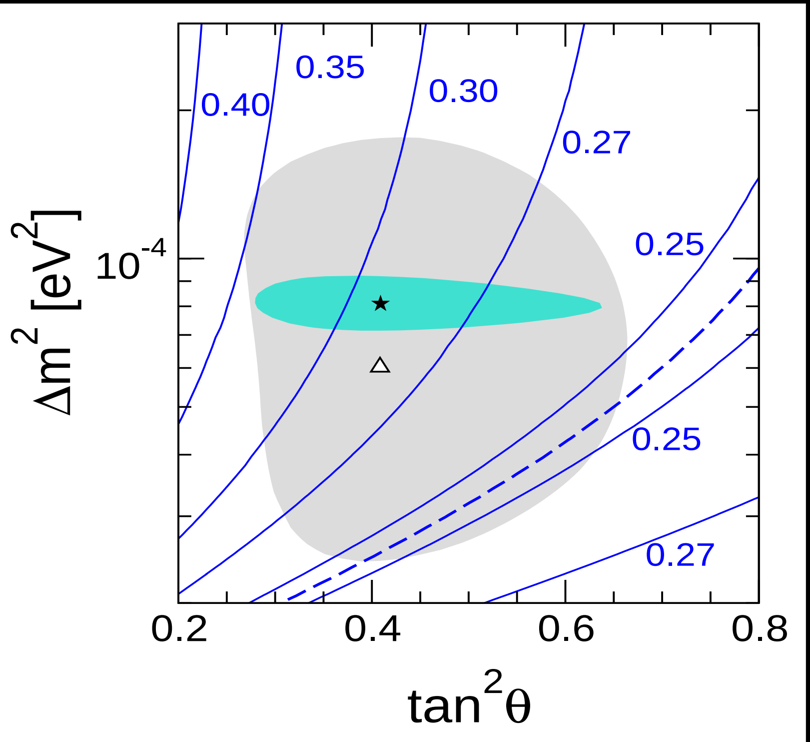
horizontal black line is current NSI limit vertical grey band: sensitivity without NSI

LOW ENERGY NEUTRINOS

two tasks for Borexino? KamLAND?

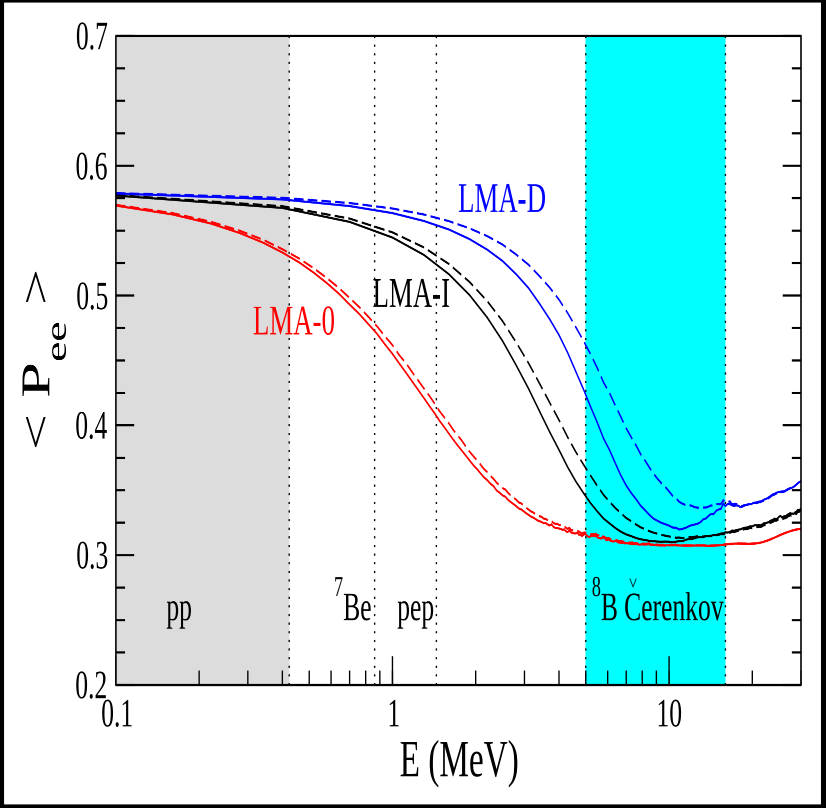
• probe nu-magn moment

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



• probe NSI

Miranda et al hep-ph/0406280 JHEP



NSI-frag

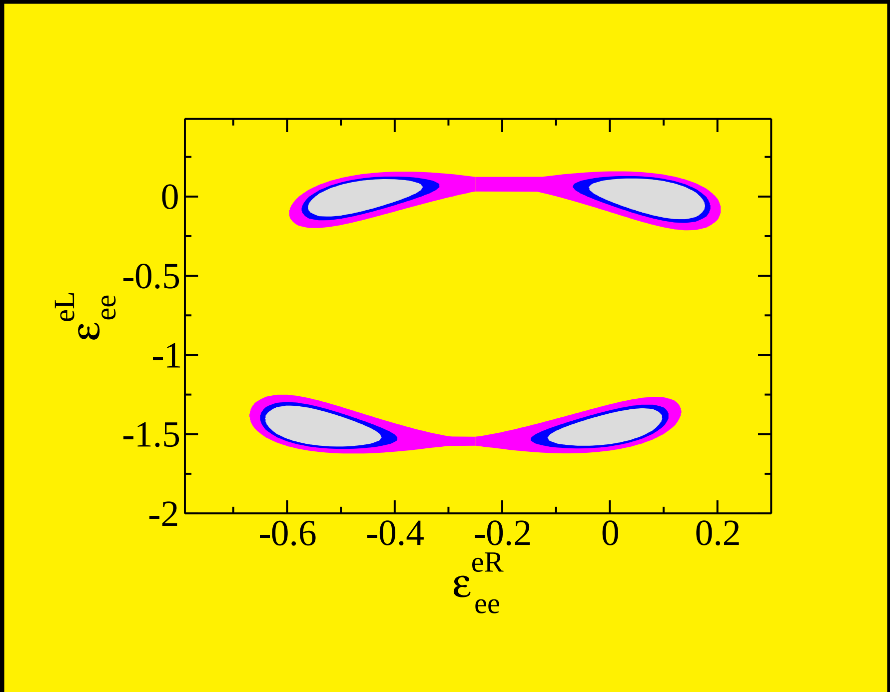
new frontier ... θ_{13}, new neutral gauge bosons, etc ⇐

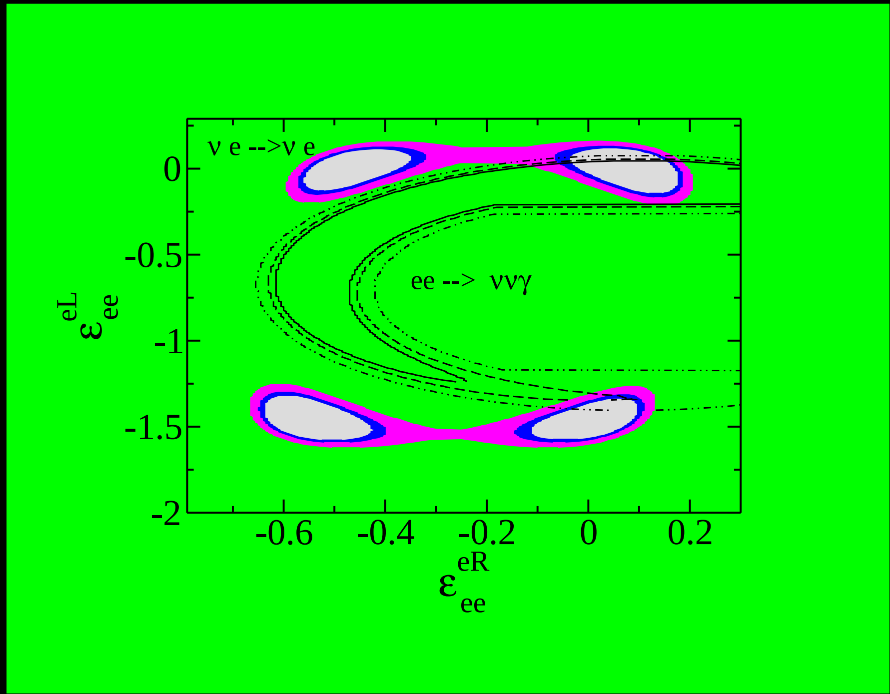
NSI with electrons

$\nu - e$ scattering data constrain 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?

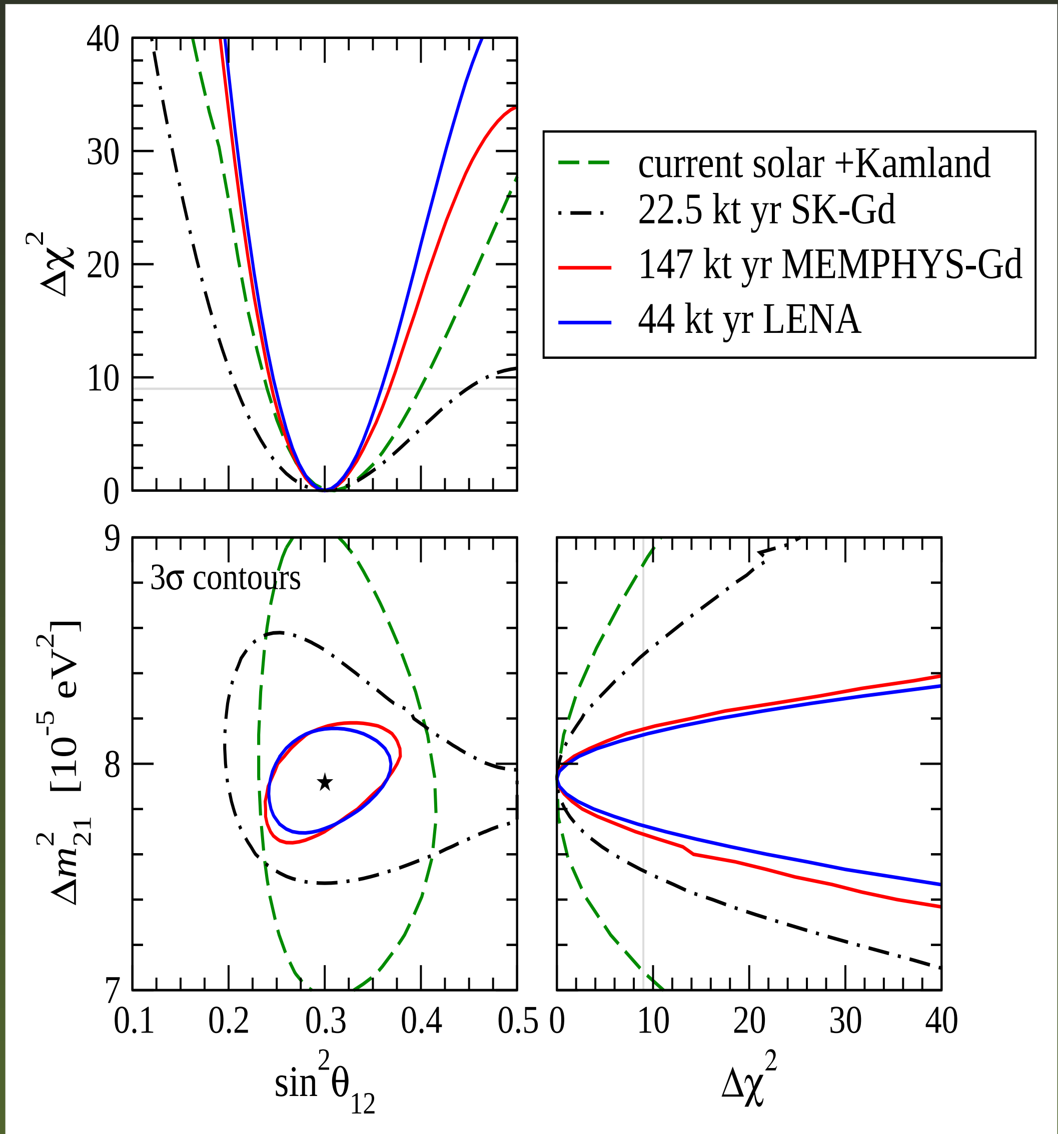
$\Rightarrow$





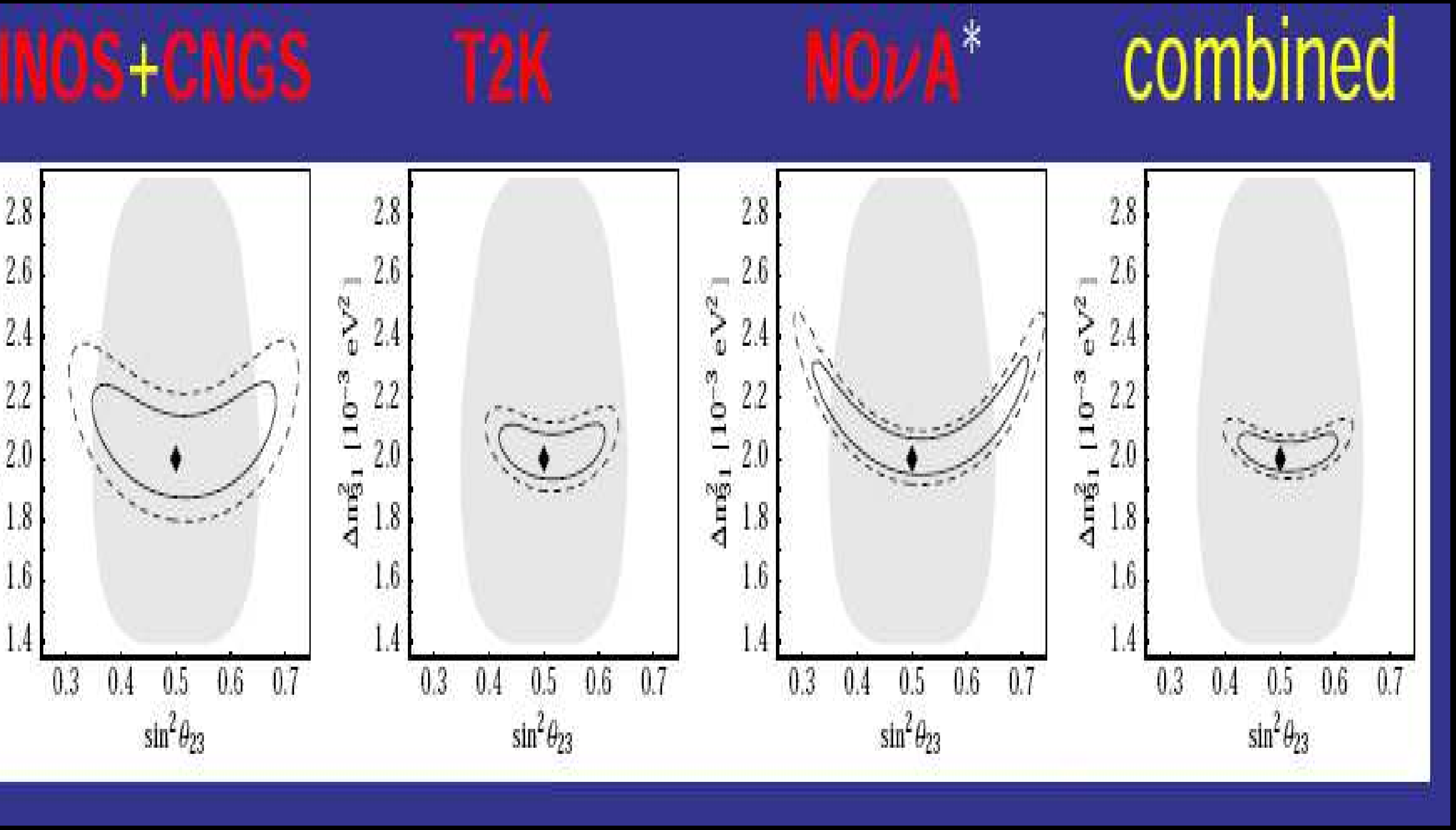
improving on solar parameters

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



courtesy of T. Schwetz **Global**

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 Global

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 ●

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  - 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

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- a theory of flavour?

PATHWAYS TO NU-MASS

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- what is the mechanism?
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  - B-L gauged vs ungauged...
- what is the scale ?
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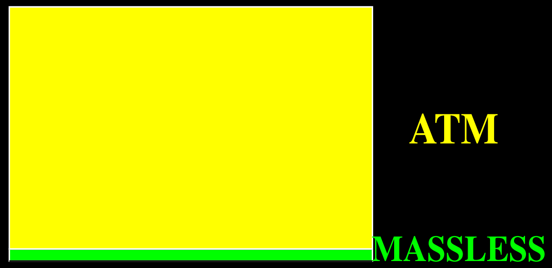
  - Intermediate scale seesaw: P-Q, L-R ...
  - Weak scale (inverse) seesaw
- a theory of flavour?
- phenomenological m-nu hints other than oscillations?
  "generic": LFV $\mu \to e\gamma$, $\tau \to \mu\gamma$, mu-e conversion in nuclei, ...

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

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

NU–MASSES FROM LOW–ENERGY SUSY?

- **weak-scale seesaw atm scale**

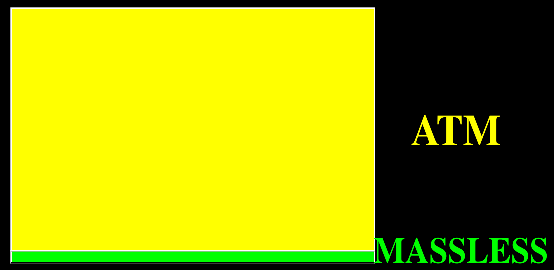


Diaz etal PRD68 (2003) 013009, PRD62 (2000) 113008; D65 (2002) 119901; PRD61 (2000) 071703

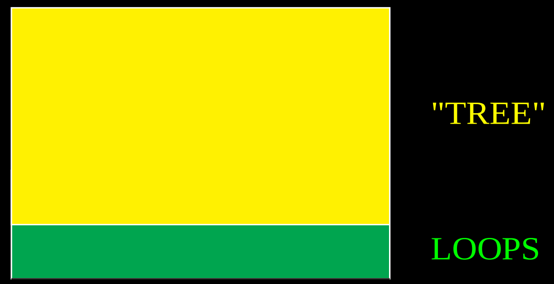
theoretical origin

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

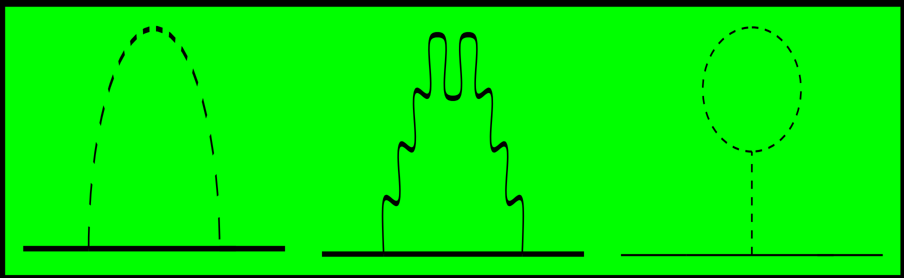
NU–MASSES FROM LOW–ENERGY SUSY?



- **weak-scale seesaw** atm scale



- **radiative** solar mass scale



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http://ahep.uv.es/

TESTING NU-MIXING

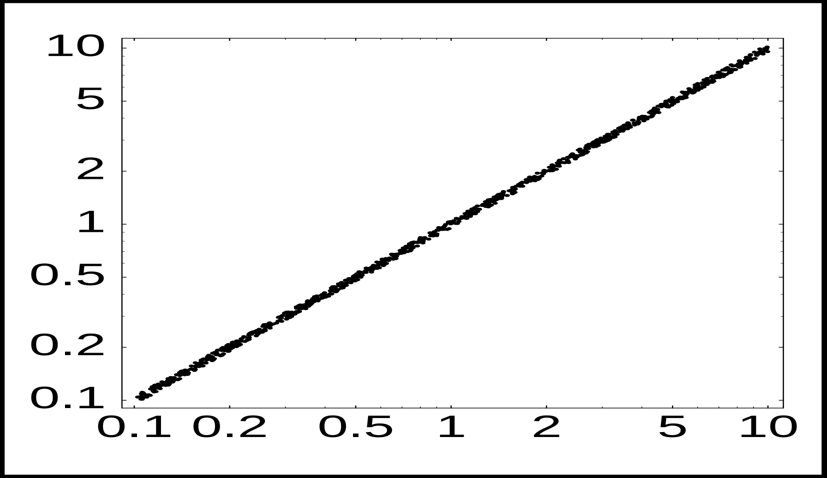
AT ACCELERATORS, eg LHC

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**



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

TESTING NU–MIXING ANGLES at LHC/ILC

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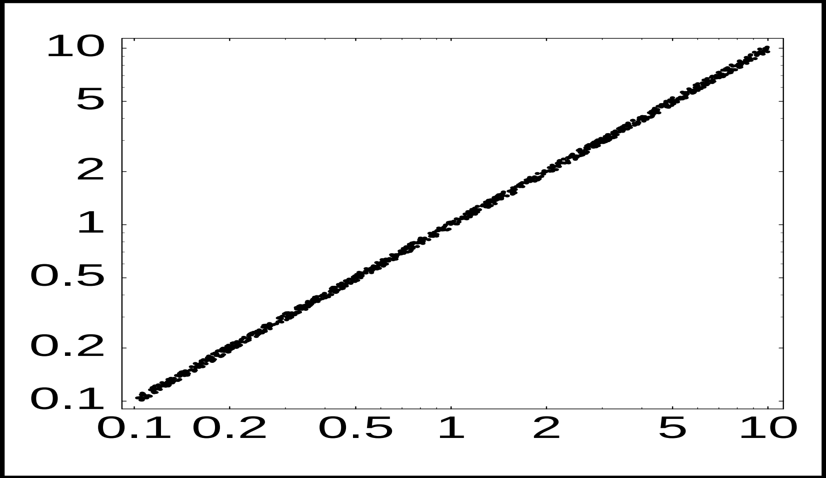


$\frac{BR(\chi \to \mu W)}{BR(\chi \to \tau W)}$ **vs** $\tan^2_{\text{atm}}$

- **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

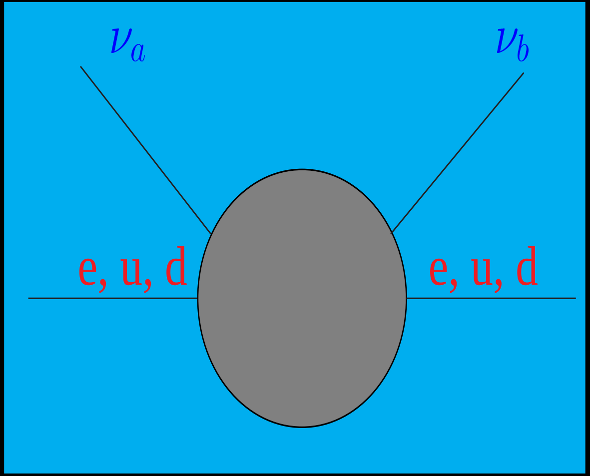
model-independent SEESAW, CC, NC & NSI

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 $\Leftarrow$

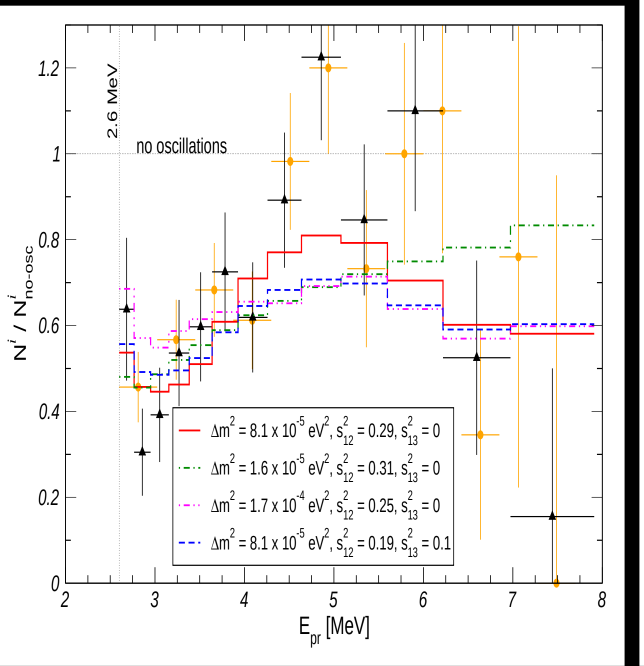
- **CC & NC source of gauge-induced NSI**

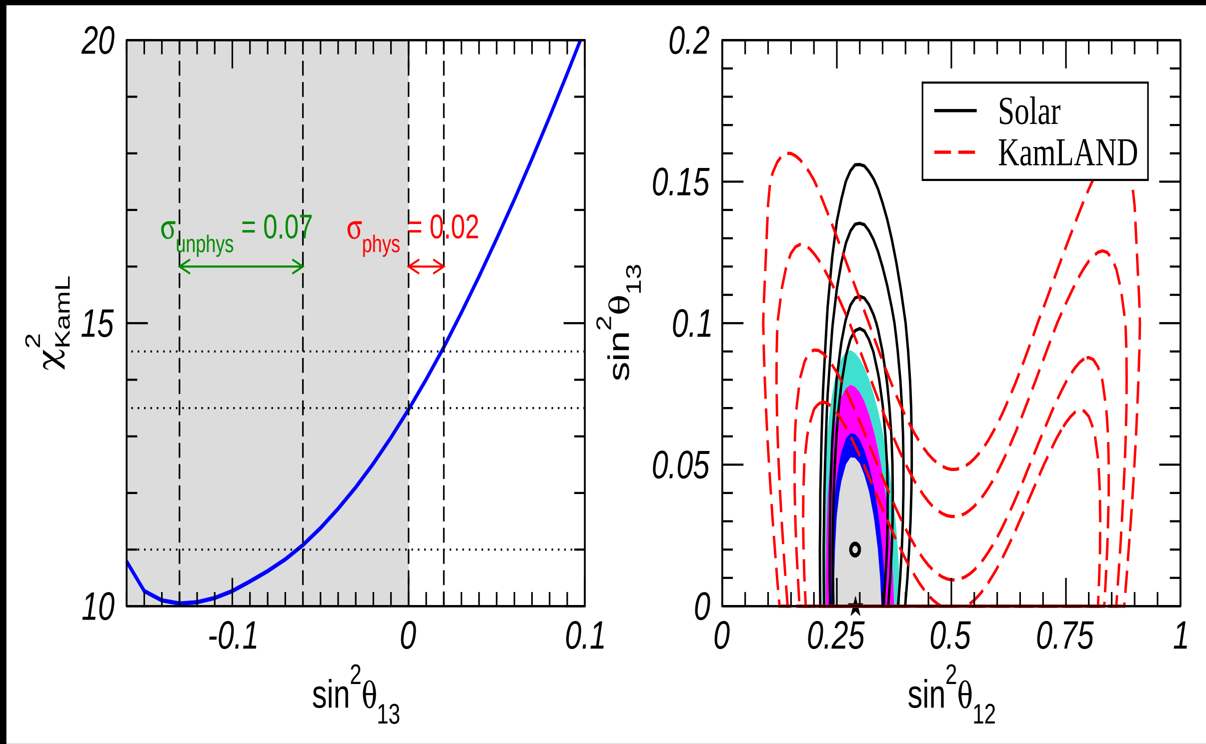
why KamLAND04 improves θ_{13}

⇐

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

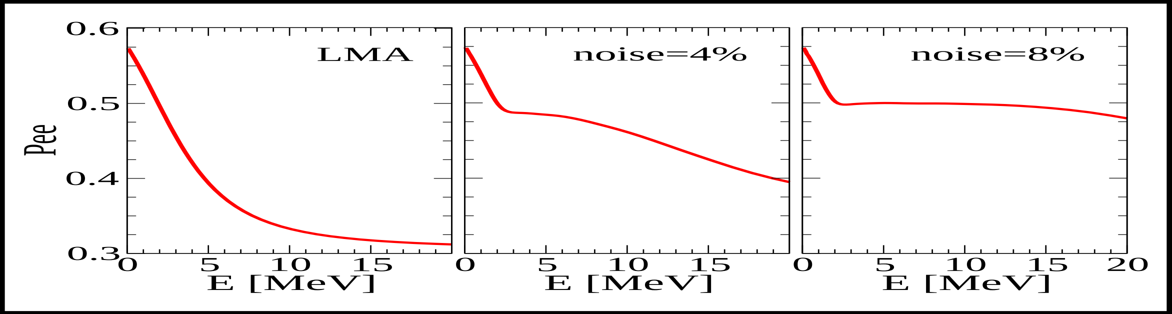
Nunokawa et al NPB472 (1996) 495

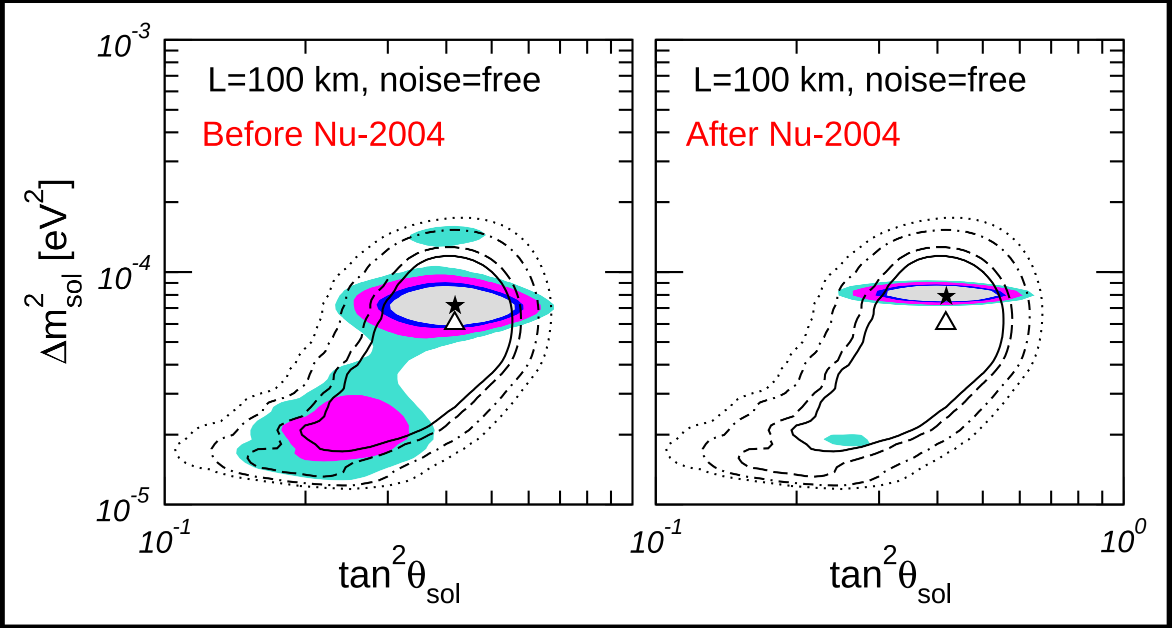
Burgess et al 97

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

& JCAP 0401 (2004) 007

Guzzo et al, Balantekin et al





despite such large distortion

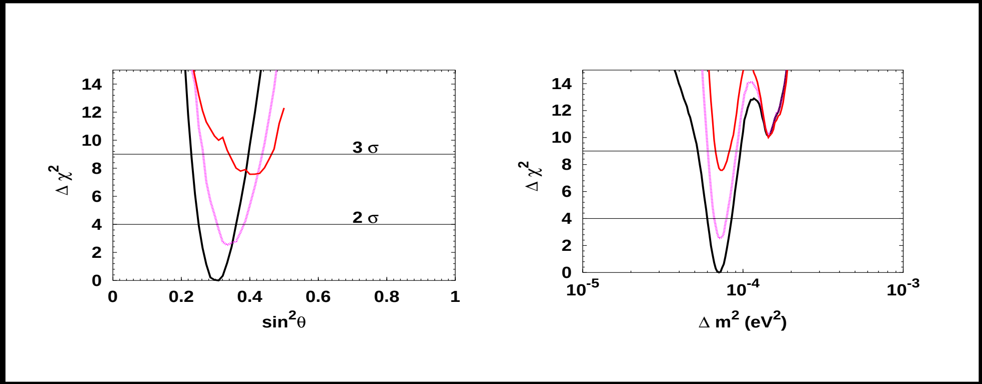
determination is robust

Maltoni et al, hep-ph 0405172

noisy Sun

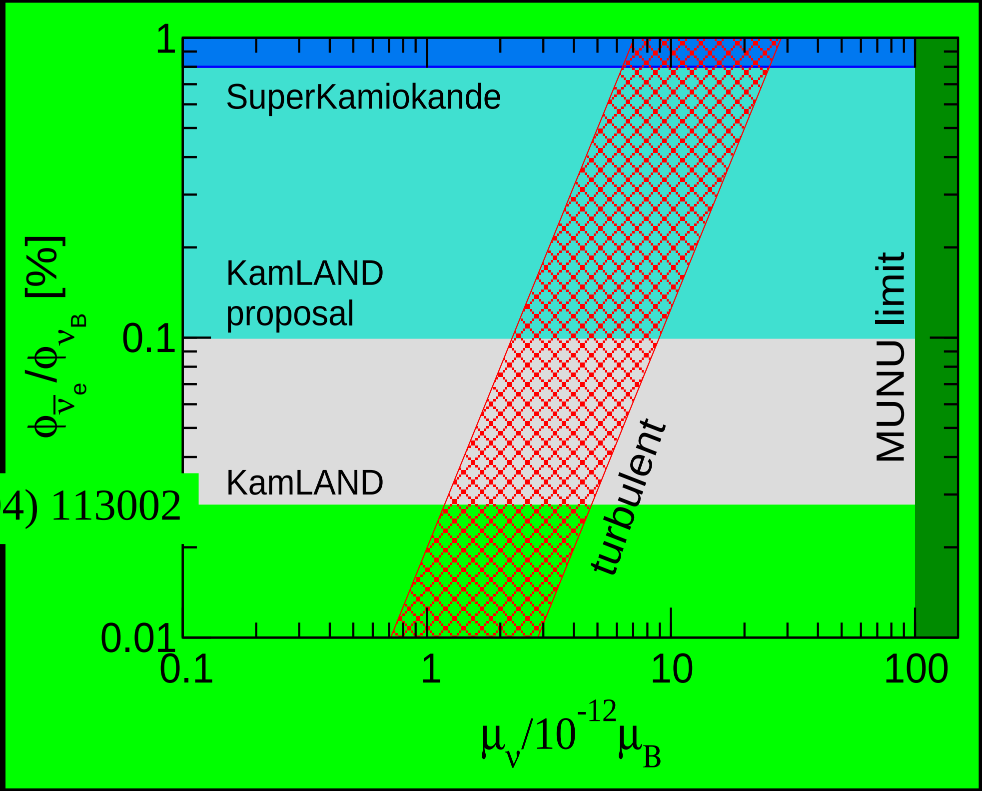
ROBUSTNESS of SOLAR-nu oscillations wrt SFP

ensured by absence of solar anti-nu



regular versus random mag field

isolating μ_ν from $\mu_\nu B$?



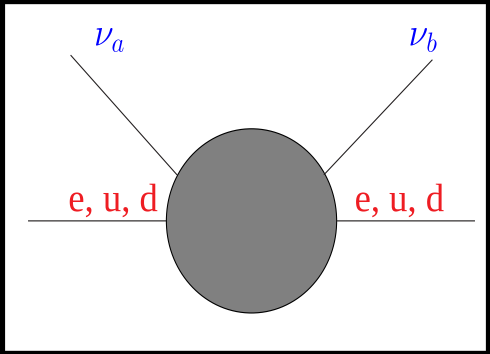
Miranda et al PRL93 (2004) 051304 & PRD70 (2004) 113002

⇐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, converting 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

NSI zoology

Non-Standard Interactions arise in most massive neutrino models, Prog. Part. Nucl. Phys. 26 (1991) 91

gauge NSI arise in seesaw-type models rectangular CC lepton mixing matrix and non-diagonal NC, PRD22 (1980) 2227

may lead to sizeable flavor and CPV even in massless neutrino limit

scalar NSI arise in radiative models of neutrino mass, Zee or Babu, etc

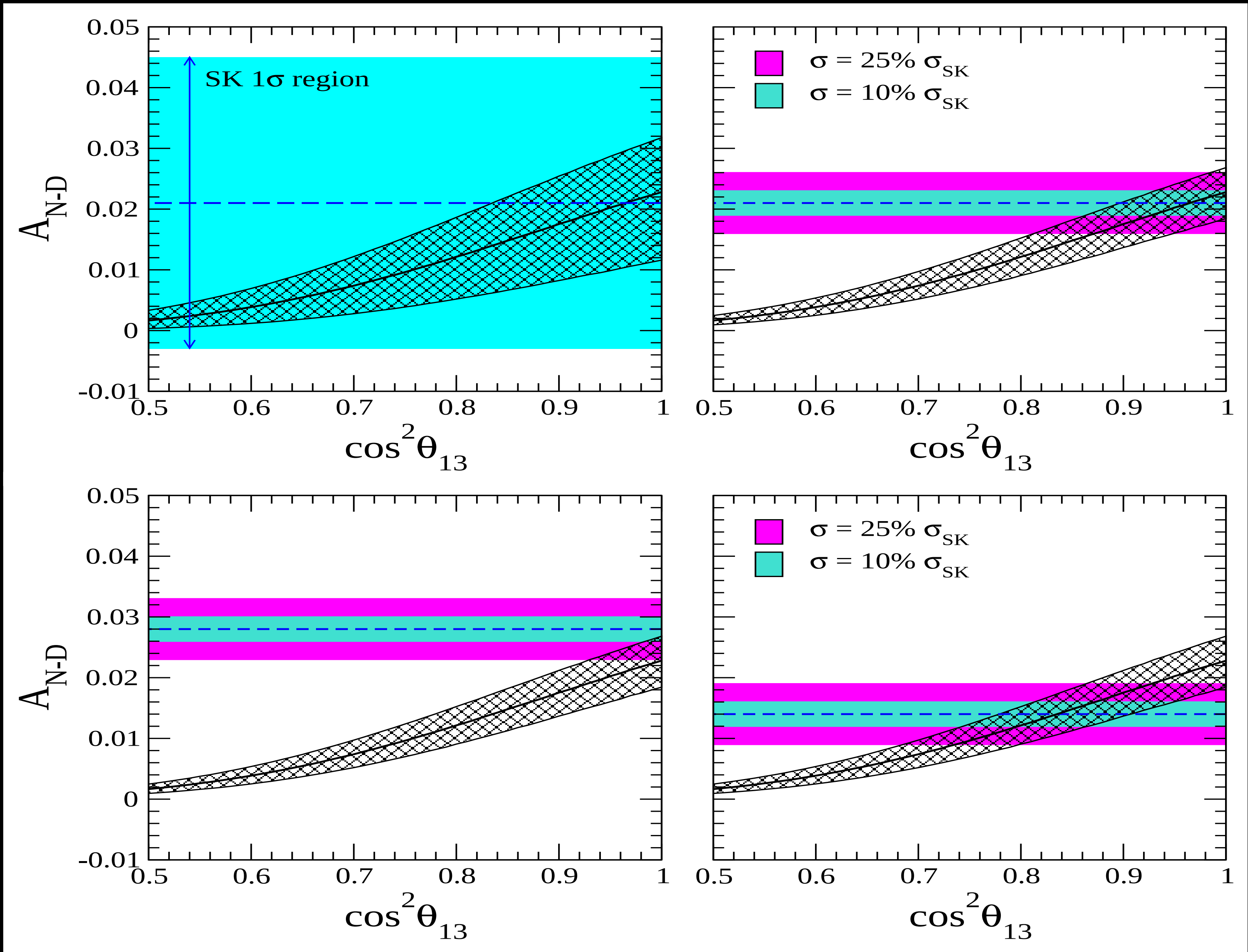
majoron emitting neutrino decays

Chikashige, Mohapatra, Peccei Schechter, JV PR D25 (1982) 774; JV PLB131 (1983) 87; Gelmini, JV, etc

DAY-NIGHT EFFECT WITH 3 NEUTRINOS

Akhmedov, Tortola, JV, JHEP05 (2004) 057

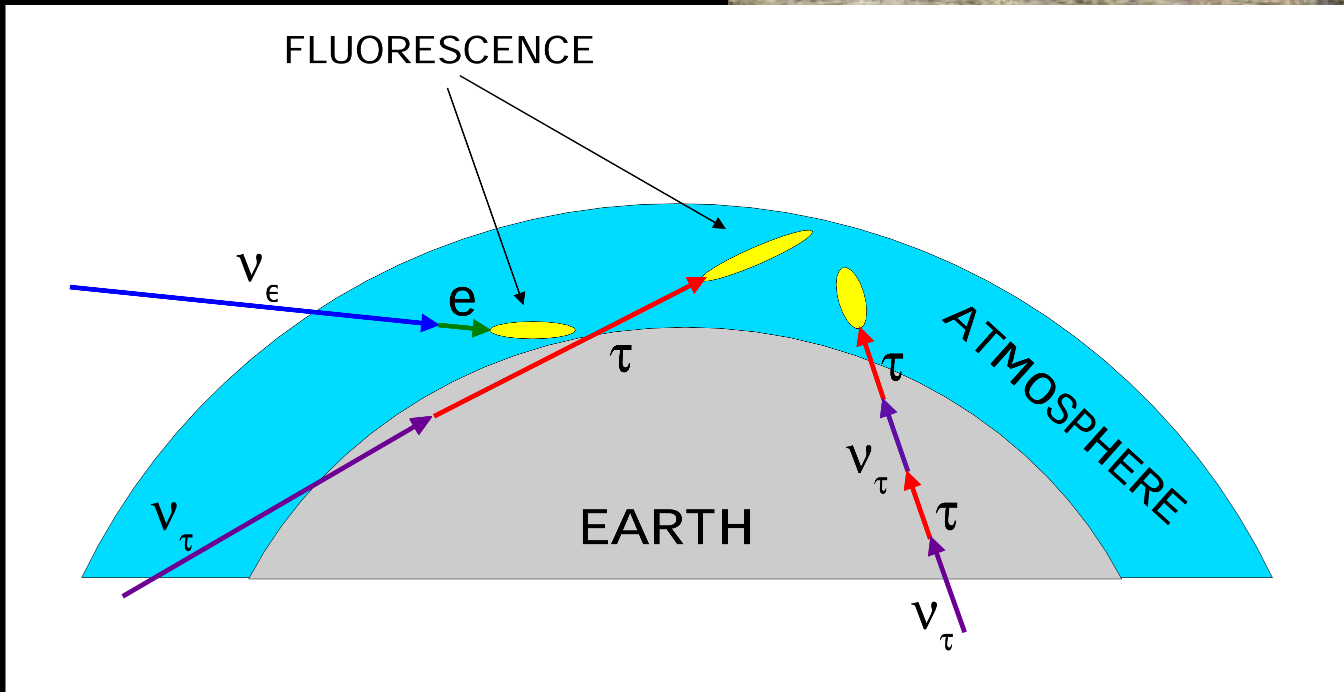
⇐



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 NEUTRINOS

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

HIGH ENERGY NEUTRINOS

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- **accelerated primaries make pions $\Rightarrow \Phi_\gamma \sim \Phi_\nu$ due to isospin**

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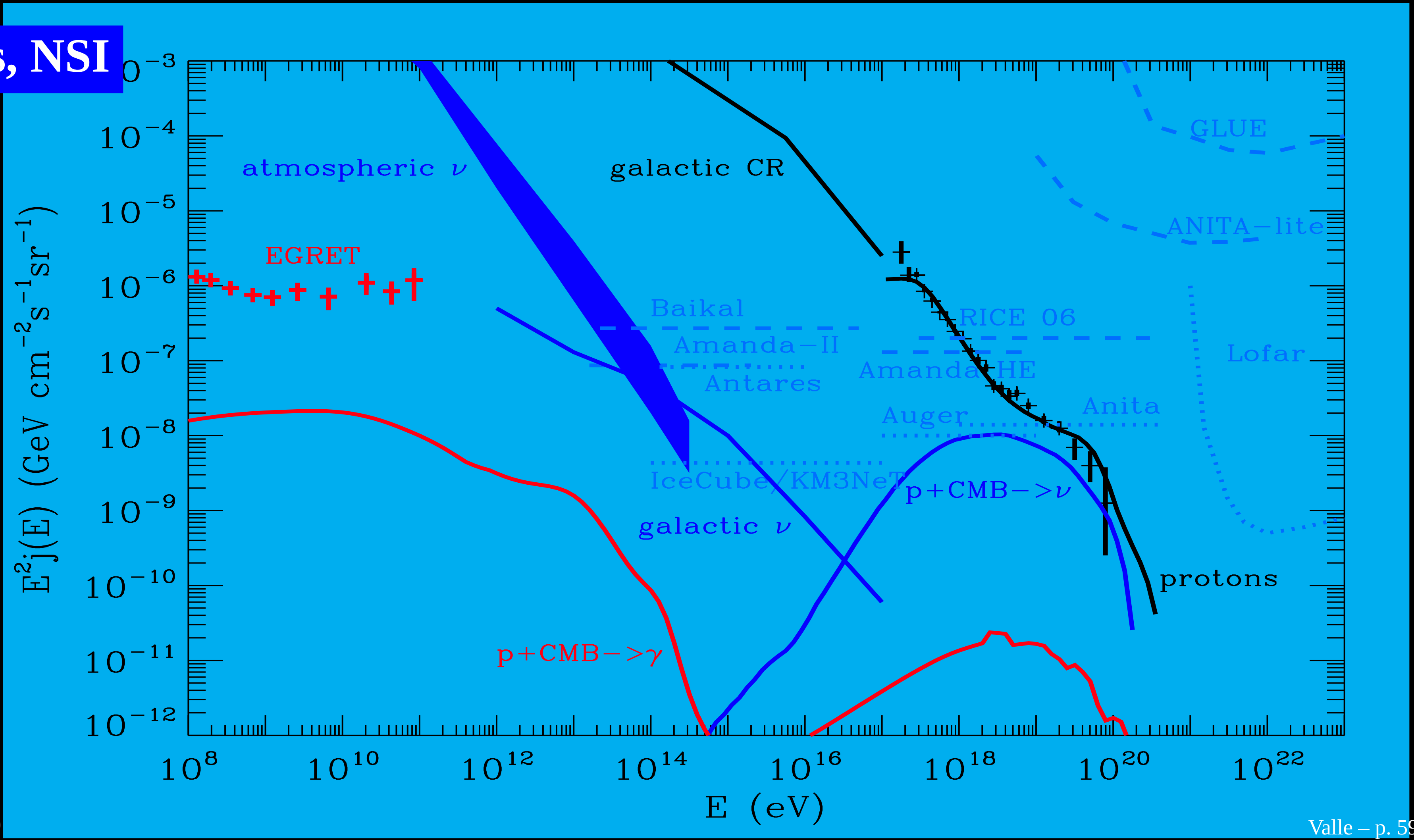
- **expect nu's with higher energies, eg AGN, GRB ..**
- **accelerated primaries make pions $\Rightarrow \Phi_\gamma \sim \Phi_\nu$ due to isospin**
- **nu-spectrum unmodified** **sources & nu-properties**

flavor ratios, NSI

synergy $\Rightarrow$

Sigl $\Rightarrow$



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