INT July 99

ν physics 99

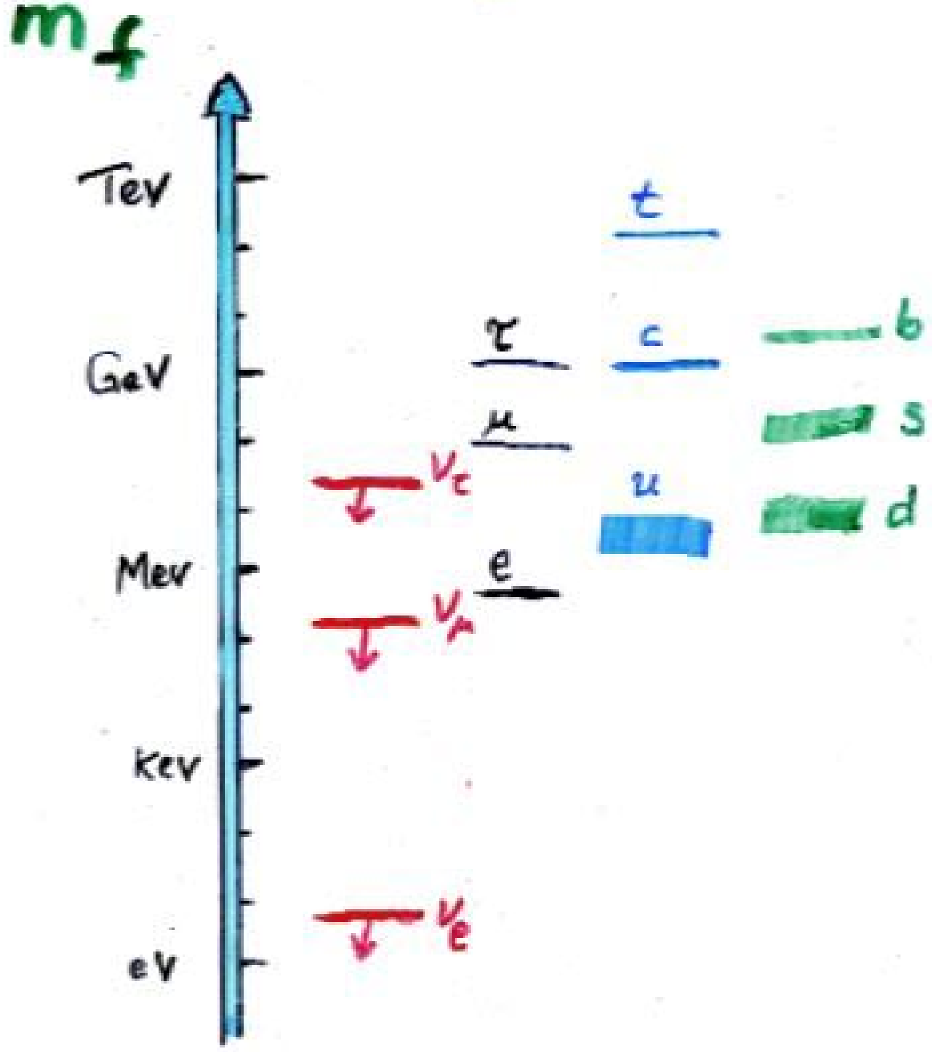
José W. F. Valle

http://neutrinos.uv.es

- theory of m_ν
  - solar & atm hints
    - reconciling $\odot$ & atm
      - adding HDM
        - adding LSND
- role of m_ν & alternatives

ν puzzles

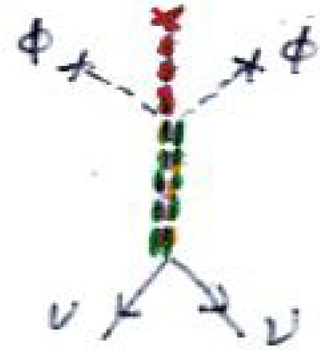
- why massless?
- what makes $m_\nu \ll m_{q,e}$? } ?
- $\nu = \bar{\nu}$? } ?



Unification & seesaw

Gelman, Ramond Slansky

$m_\nu \propto \frac{1}{v_R}$



ver seesaw

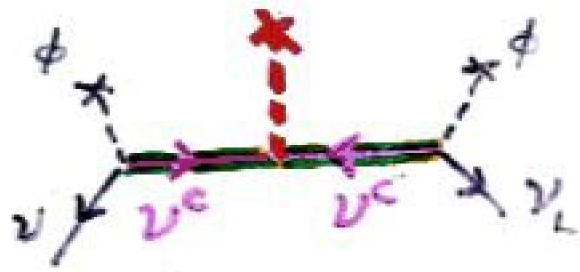
SO_{10}

$\begin{pmatrix} u & \nu & u^c & \nu^c \\ d & e & d^c & e^c \end{pmatrix}$

Pati, Salam

$SU_4^c \times SU_2^L \times SU_2^R$

$\begin{pmatrix} u & \nu \\ d & e \end{pmatrix}$ $\begin{pmatrix} u^c & \nu^c \\ d^c & e^c \end{pmatrix}$



usual seesaw

$SU_3^c \times SU_{2L} \times SU_{2R} \times U_{1\,B-L}$

$\begin{pmatrix} u \\ d \end{pmatrix}$ $\begin{pmatrix} u^c \\ d^c \end{pmatrix}$ $\begin{pmatrix} \nu \\ e \end{pmatrix}$ $\begin{pmatrix} \nu^c \\ e^c \end{pmatrix}$

$SU_3^c \times SU_{2L} \times U_{1Y}$

$\begin{pmatrix} u \\ d \end{pmatrix}^{1/6}$ $u^{c\,(-2/3)}$ $d^{c\,(1/3)}$ $\begin{pmatrix} \nu \\ e \end{pmatrix}^{-1/2}$ $e^{c\,(1)}$

Mohapatra Senjanovic

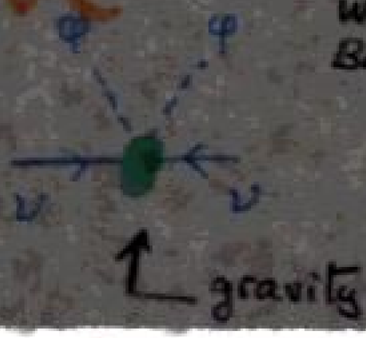
B-L violation ⇨ Parity violation

◆ m_ν & gravity scale

alternative

◆ $\begin{pmatrix}\nu\\ e\end{pmatrix}$ φ

e^c



Weinberg
Barbieri, Ellis & Gaillard

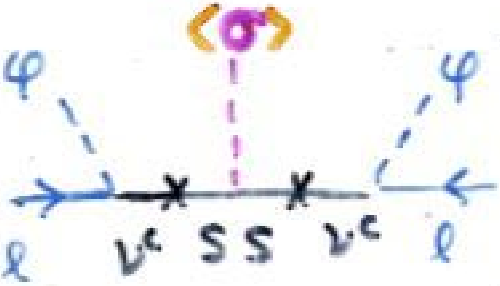
◆ m_ν & weak scale

Prog. Part. Nucl. Phys. 26 (91) 91-171

◆ $\ell \equiv \begin{pmatrix}\nu\\ e\end{pmatrix}$ φ σ

e^c

ν^c S

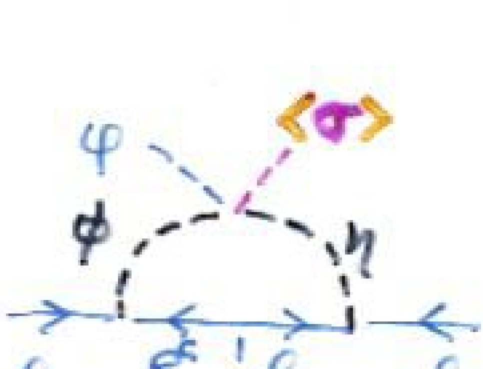


	ν_i	ν^c	S
ν_i	0	D	0
ν^c		0	M
S			$\lambda\sigma$

PLB216 (90) 360

◆ ℓ φ ϕ, η σ

e^c



Zee

◆ ℓ φ η^+ k^{++} σ

e^c

Babu

NPB397 (93) 105

$m_\nu \propto \langle\sigma\rangle$ $J \equiv \mathrm{Im}\,\sigma$ $h \to JJ$

Uncertainties in predicting m_ν

unification approach

- $\langle\sigma\rangle$ = Planck, GUT, P-Q, LR, ⋮

low-scale approach

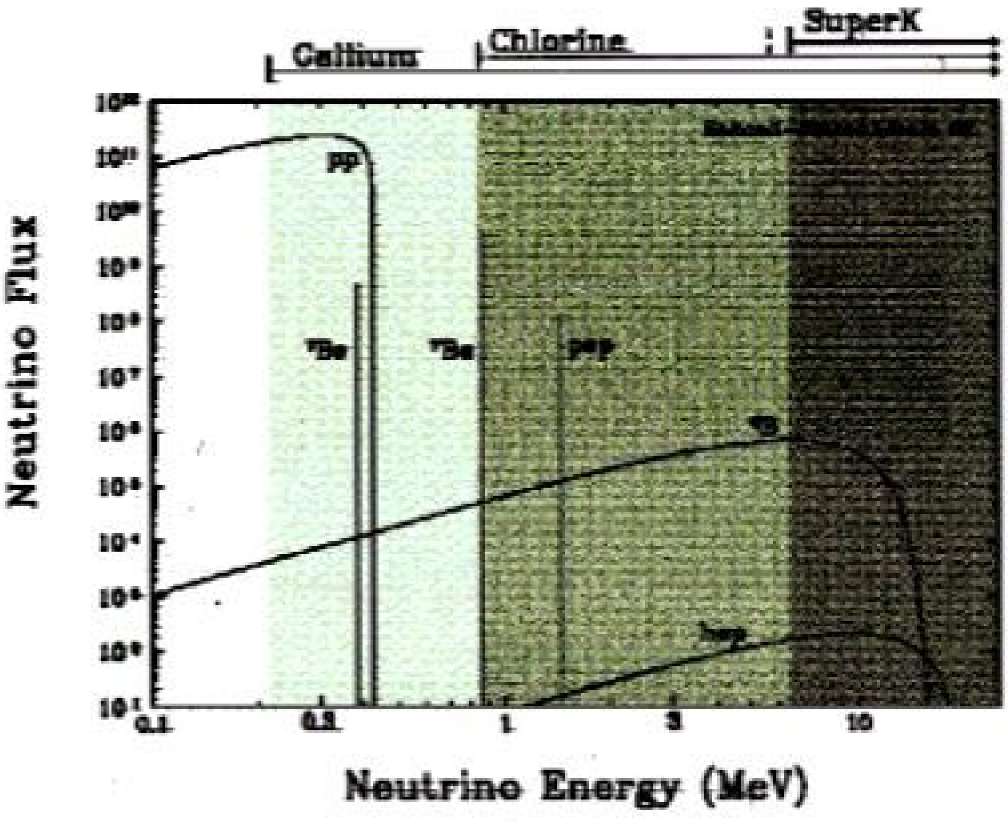
- tree-level
- 1-loop
- 2-loop

⇨ no theory for Yukawa's ⇦

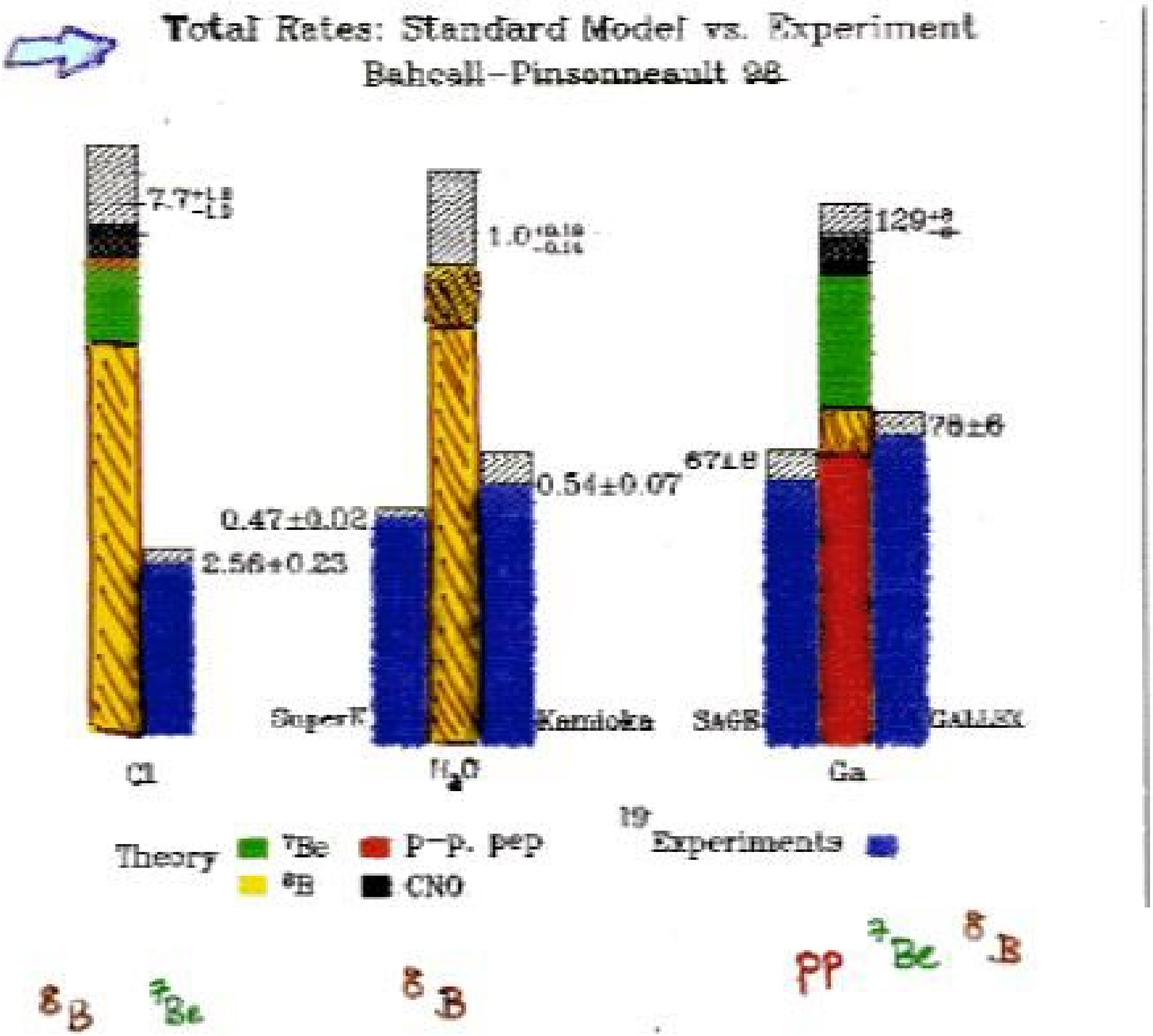
↓

need obs. input

[redacted]

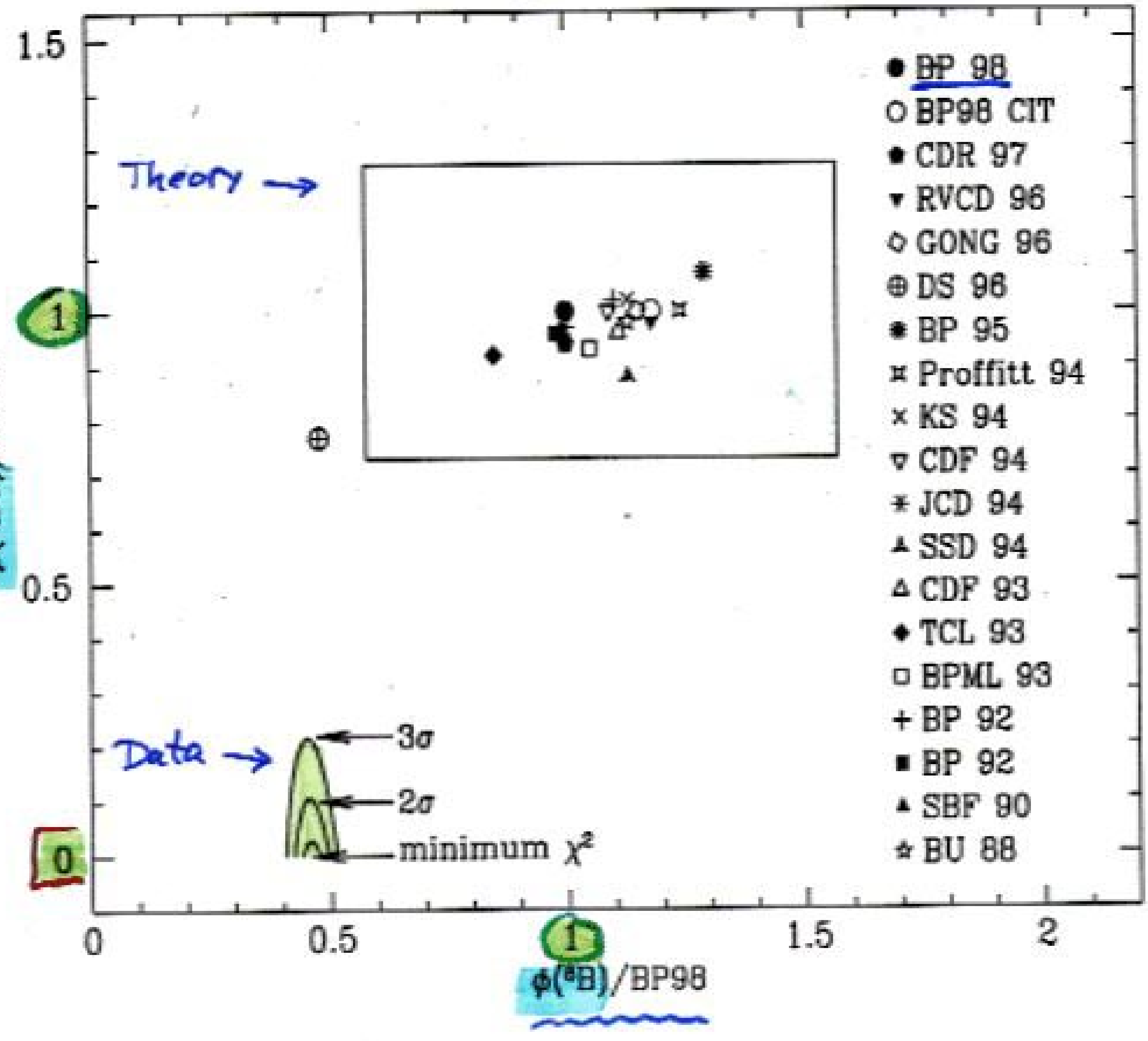


Solar neutrino energy spectrum



Solar vs

Rates

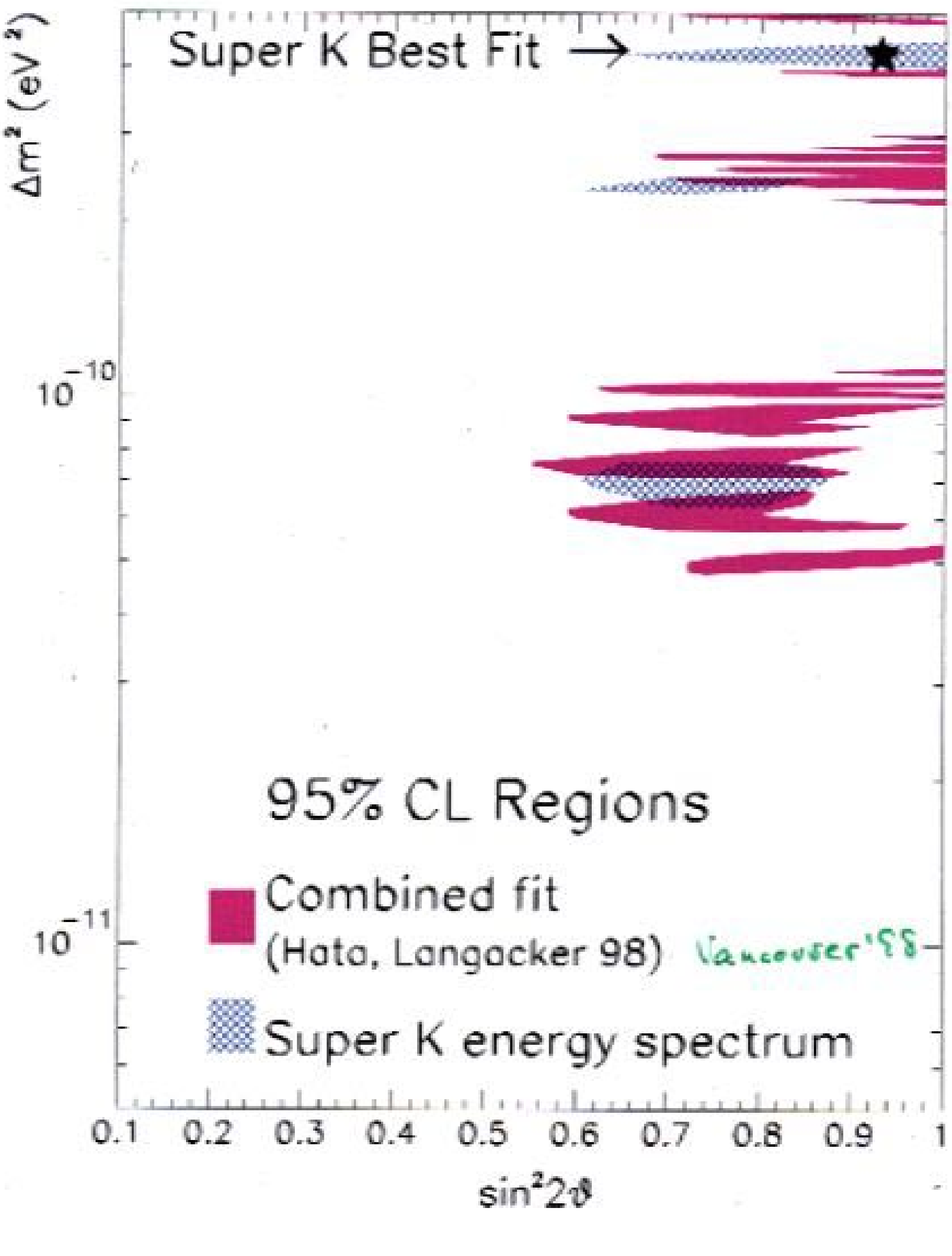


astro not a solution! ⇨

new **particle** physics

Just-so (Vacuum) oscillations

$\nu_e \rightarrow \nu_\mu, \nu_\tau$

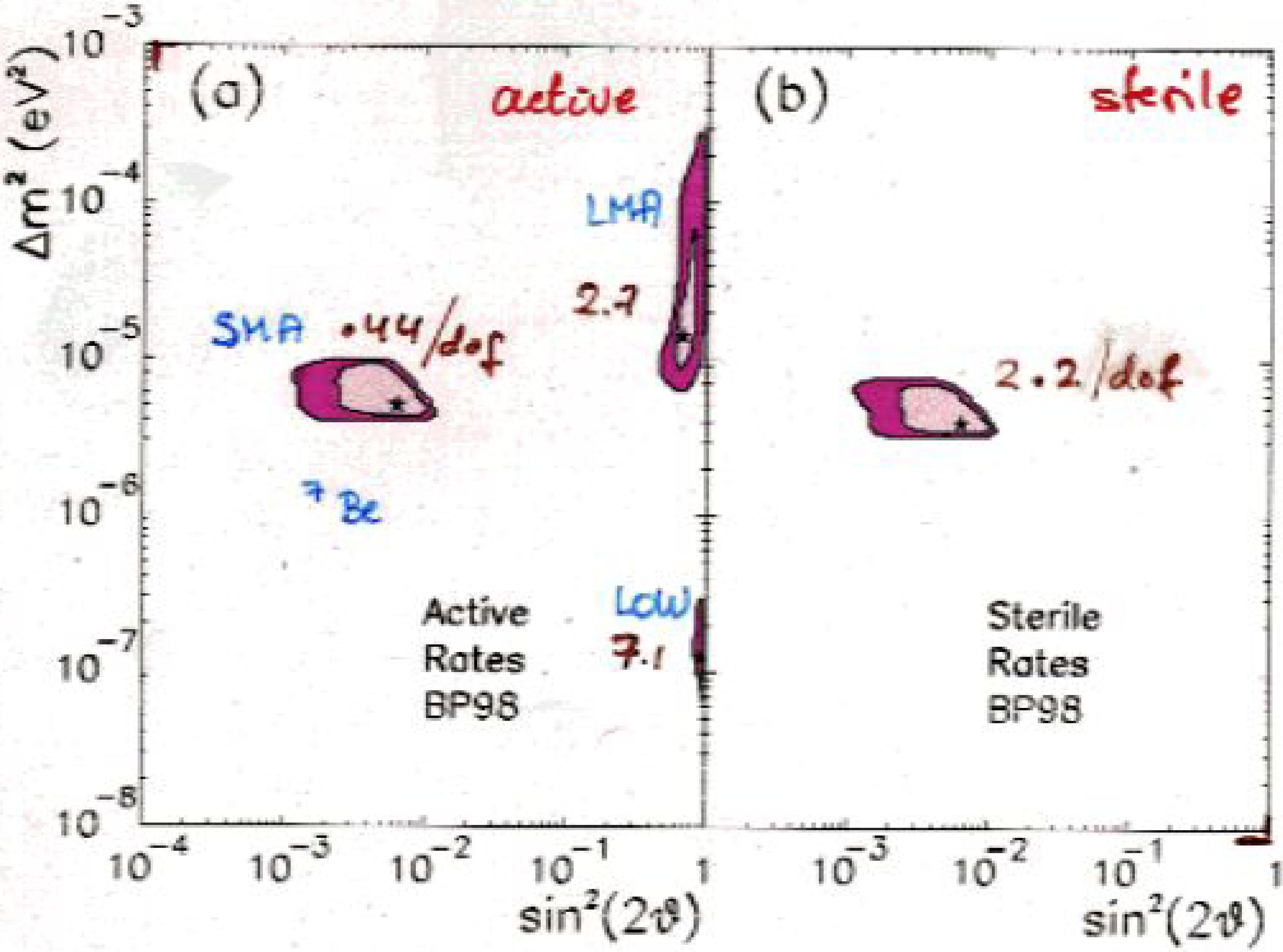


update by Barger & Whisnant '99

MSW conversions . updated analysis

Rates < Cl, H_2O, Ga   708 d

in BP98 SSM



Gonzalez-Garcia, Holanda, Peña-G, JWFV

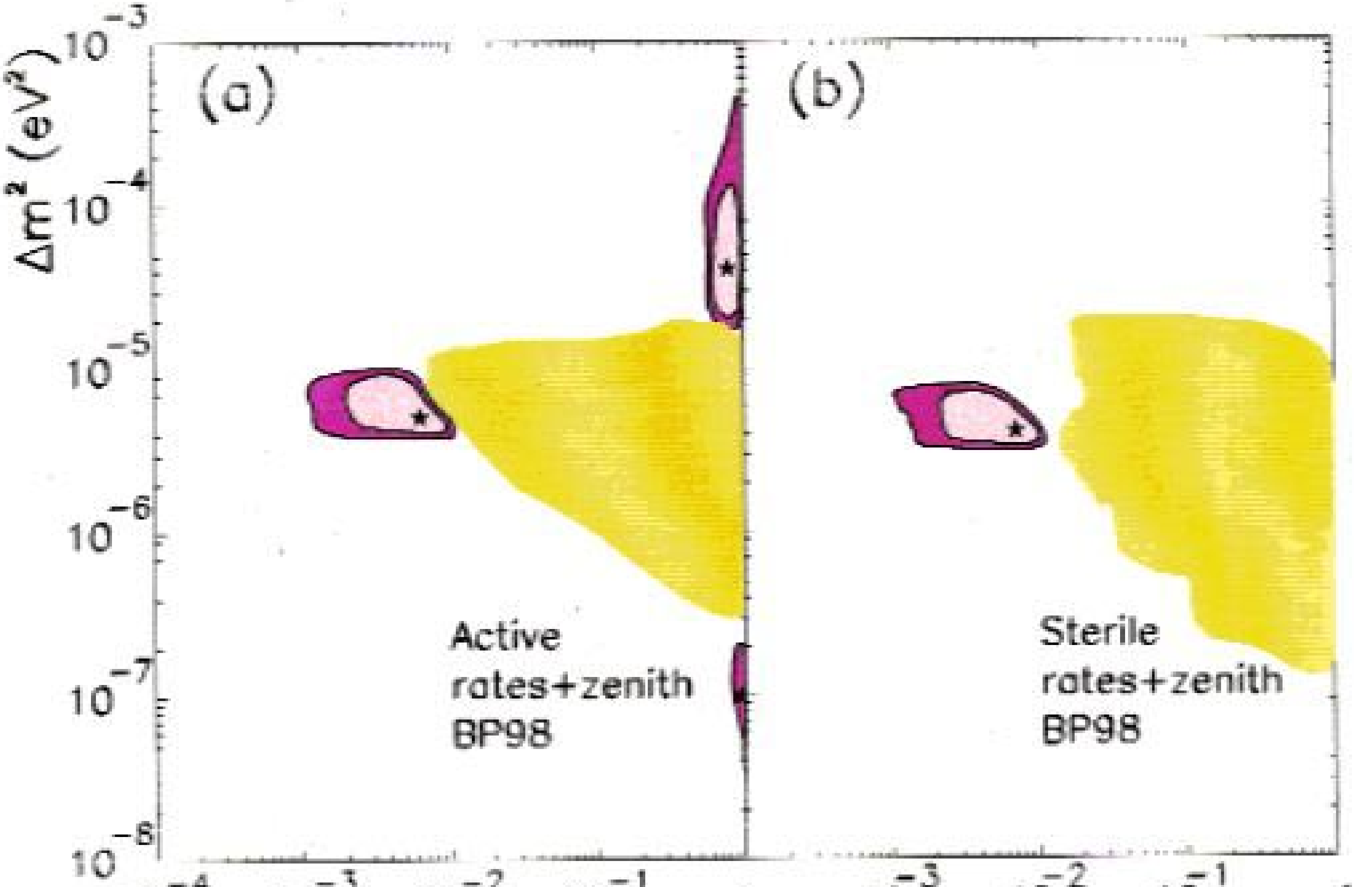
hep-ph / 9906469

Rate-indep. $\odot\nu$ observables:

- Zenith 6 D/N bins
- spectrum 18 E_e bins = 2 + 15 + 1
  5.5 6.5 >14 MeV
- seasonality 8 1.5 month bins

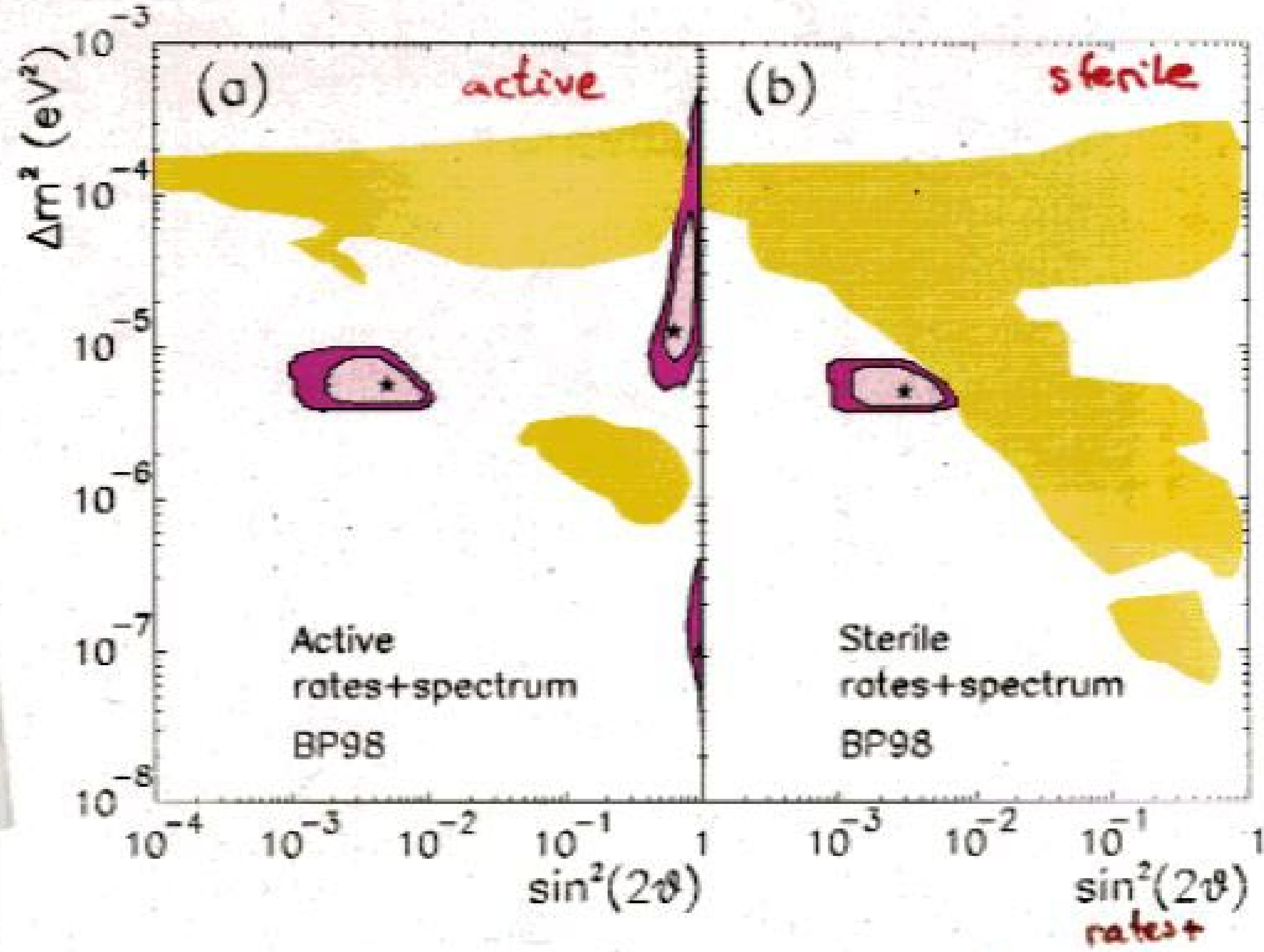
MSW 99 update in BP98 SSM

zenith



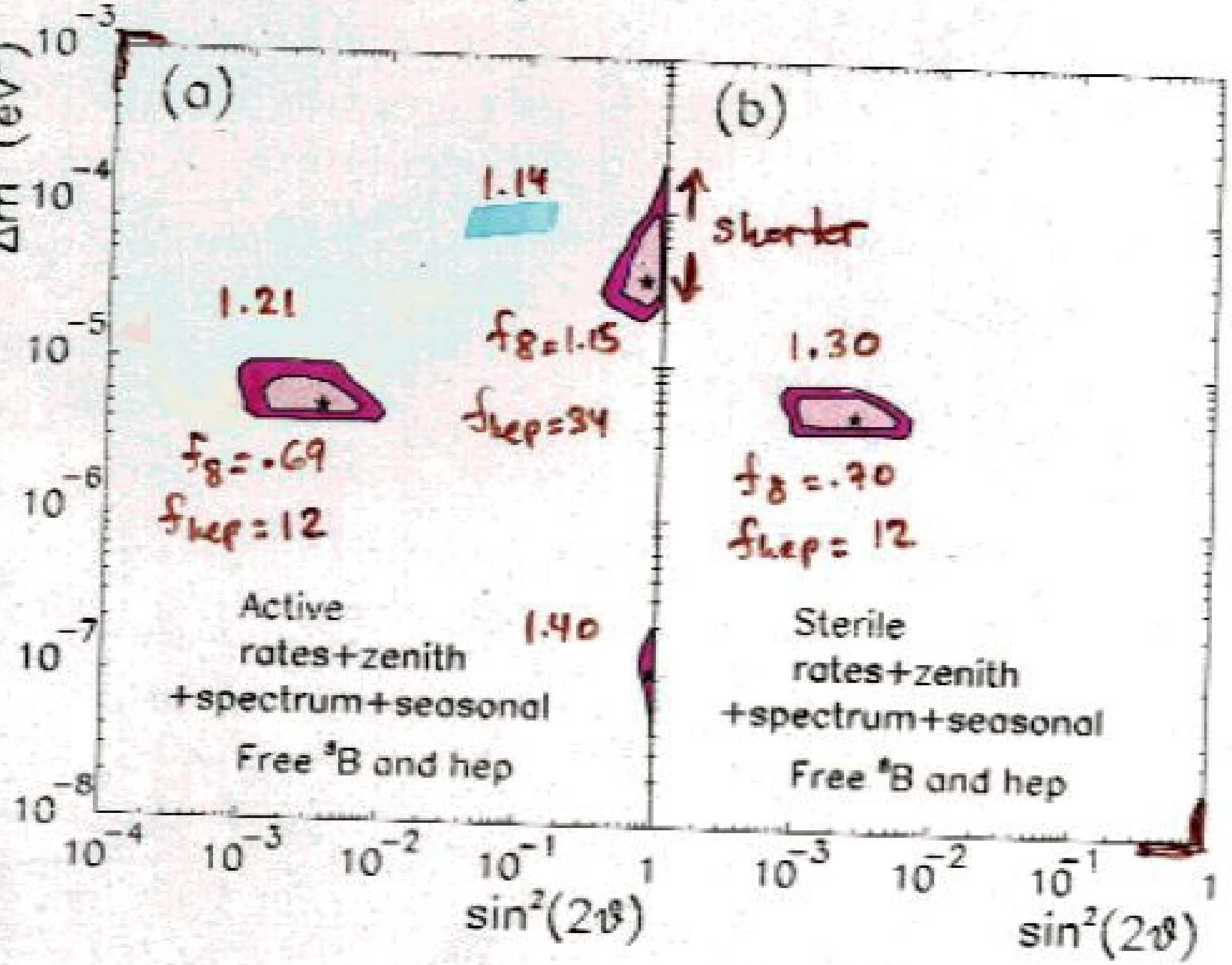
hep.ph 9906469

+ Spectrum



χ^2	rates + D/N	rates + spec.
SMA	7.3/6	23.5/18
LMA	7.9/6	24.1/18
LOW	13.8/6	27.6/18
Ster.	8.9/6	26.6/18

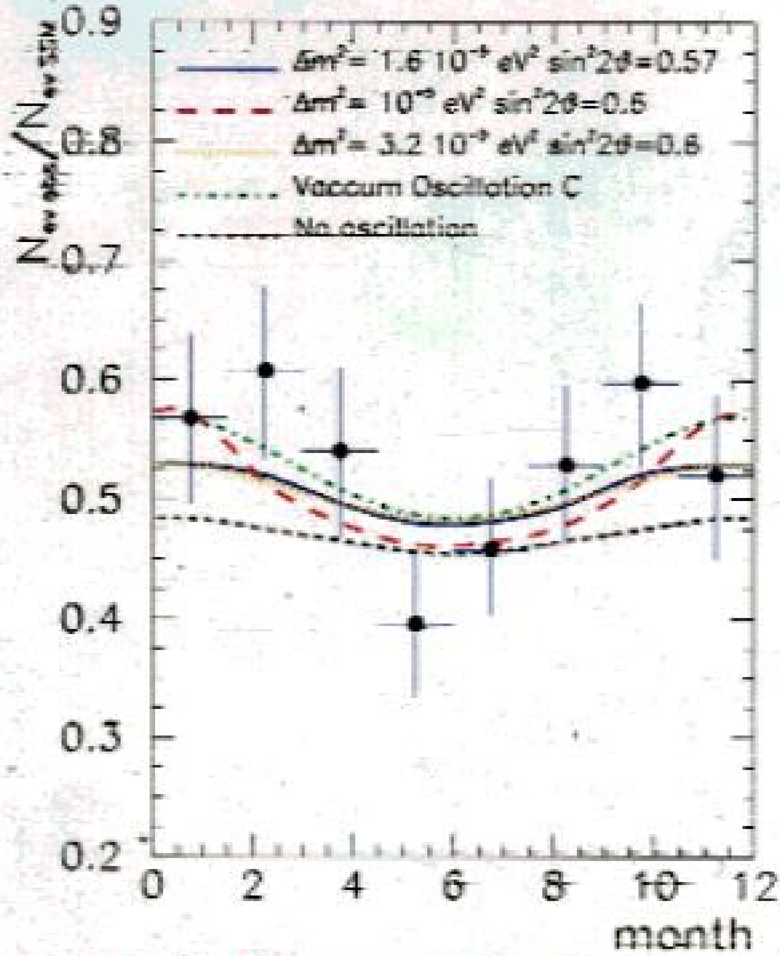
MSW 99 global free ^8B & hep



hepph/9906469

Seasonality in MSW

Holanda et al hep-ph 9903473



eccentricity ↓ intrinsic ↓

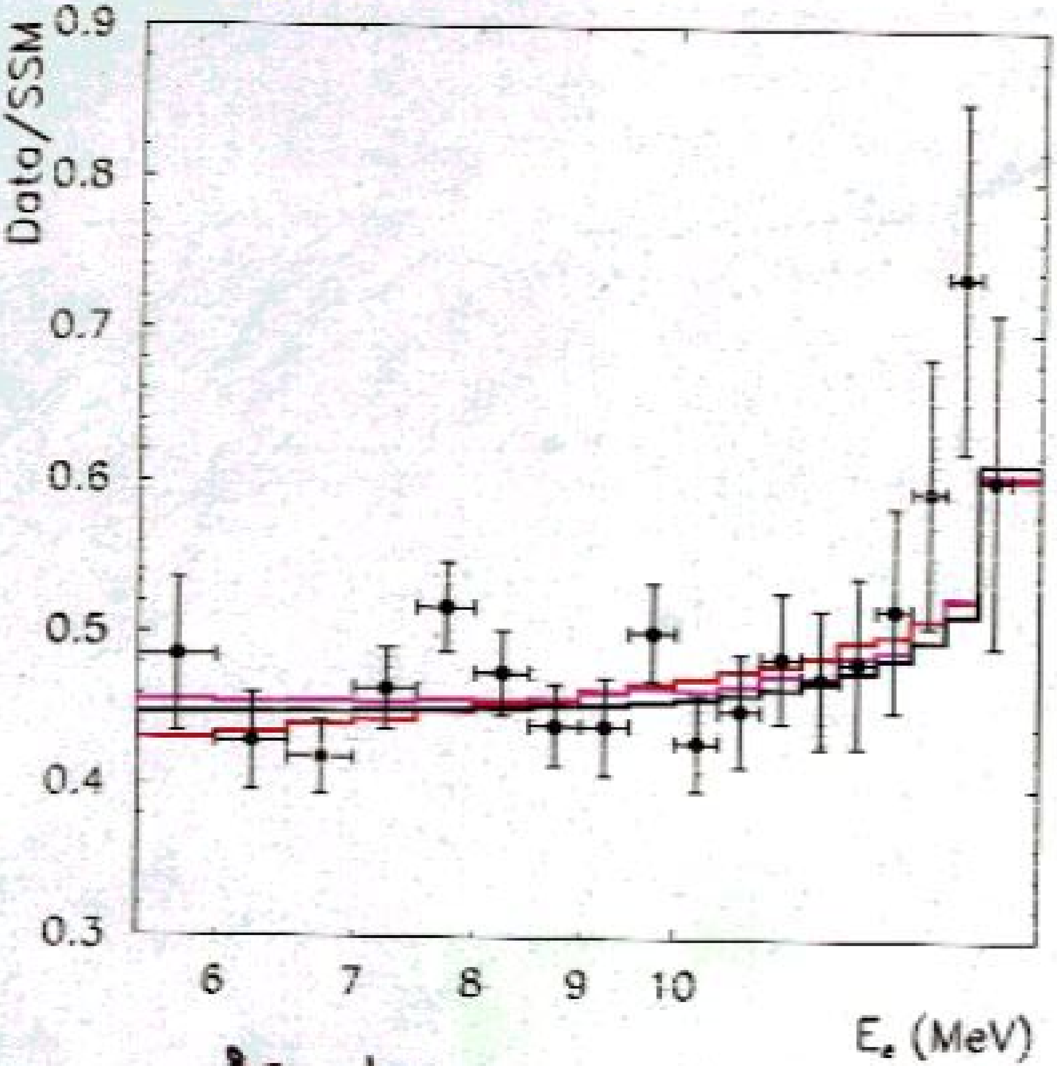
- can reach 11 = 6+5 % in LMA region allowed by D/N & spectrum

- MSW seasonality correlated with D/N

Spectrum

Gonzalez-Garcia, Holanda, Peña-Garay, JWFV.

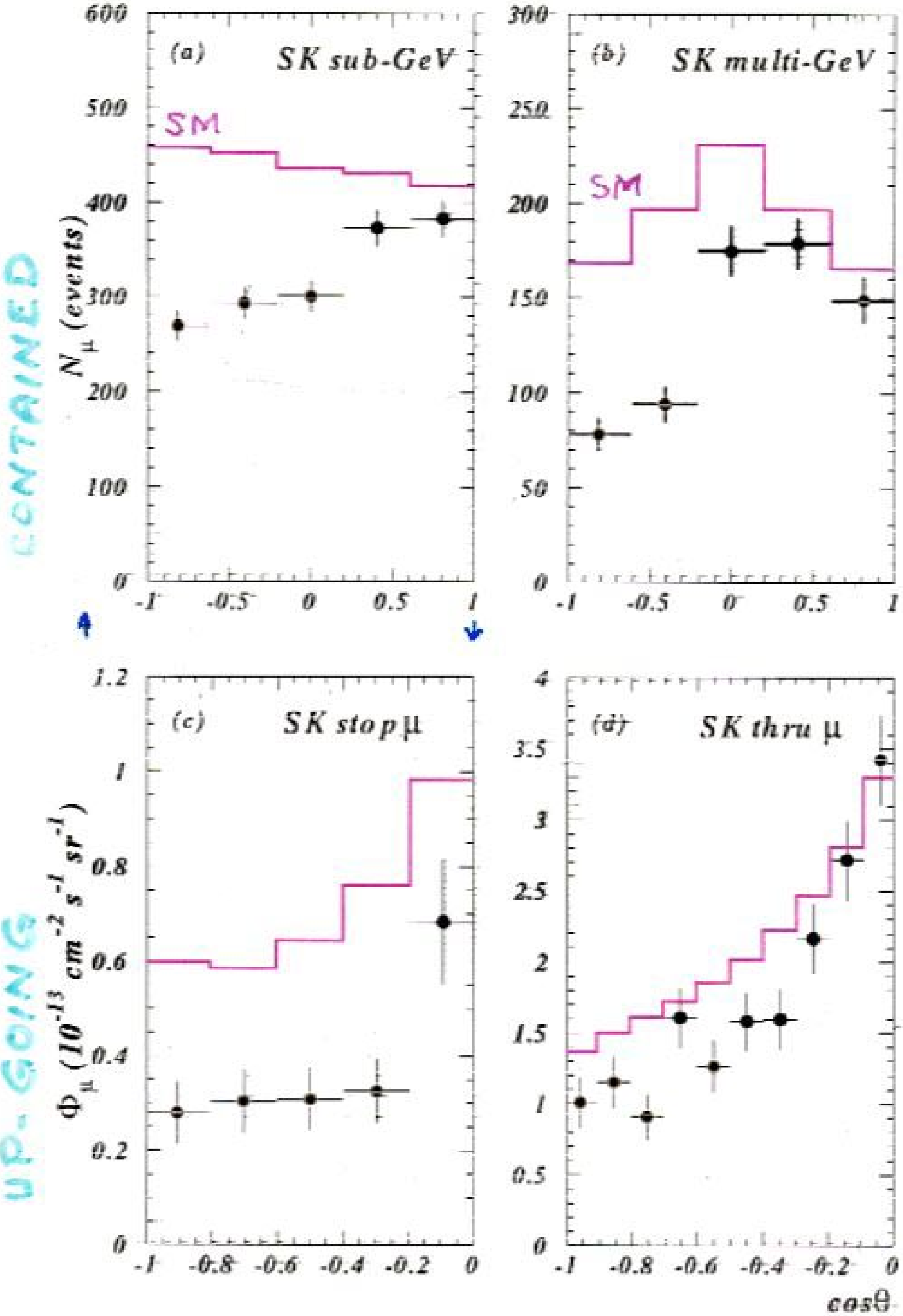
hep-ph/9906469



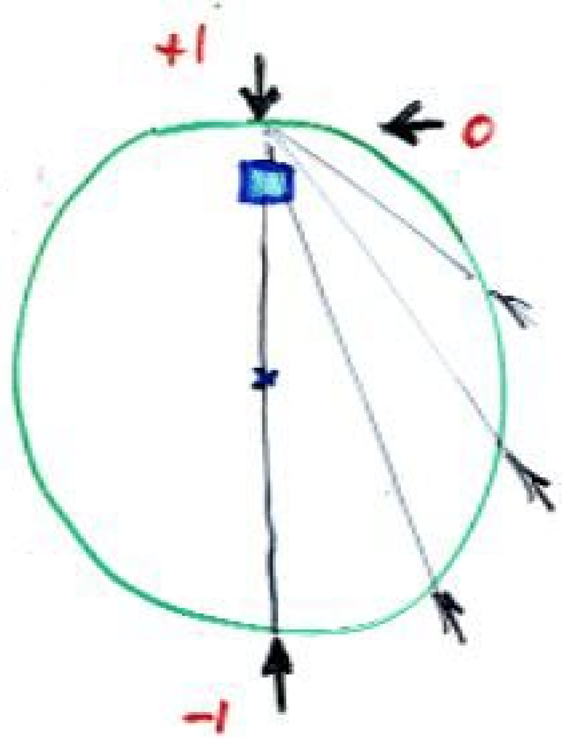
	^8B	hep
SMA	.69	12
LMA	1.15	34
no-osc	.44	14

will the hep crises wither away?

Atmospheric ν's [redacted] 7ood



origin of zenith angle-dependence
in atm. ν-oscillation scenario



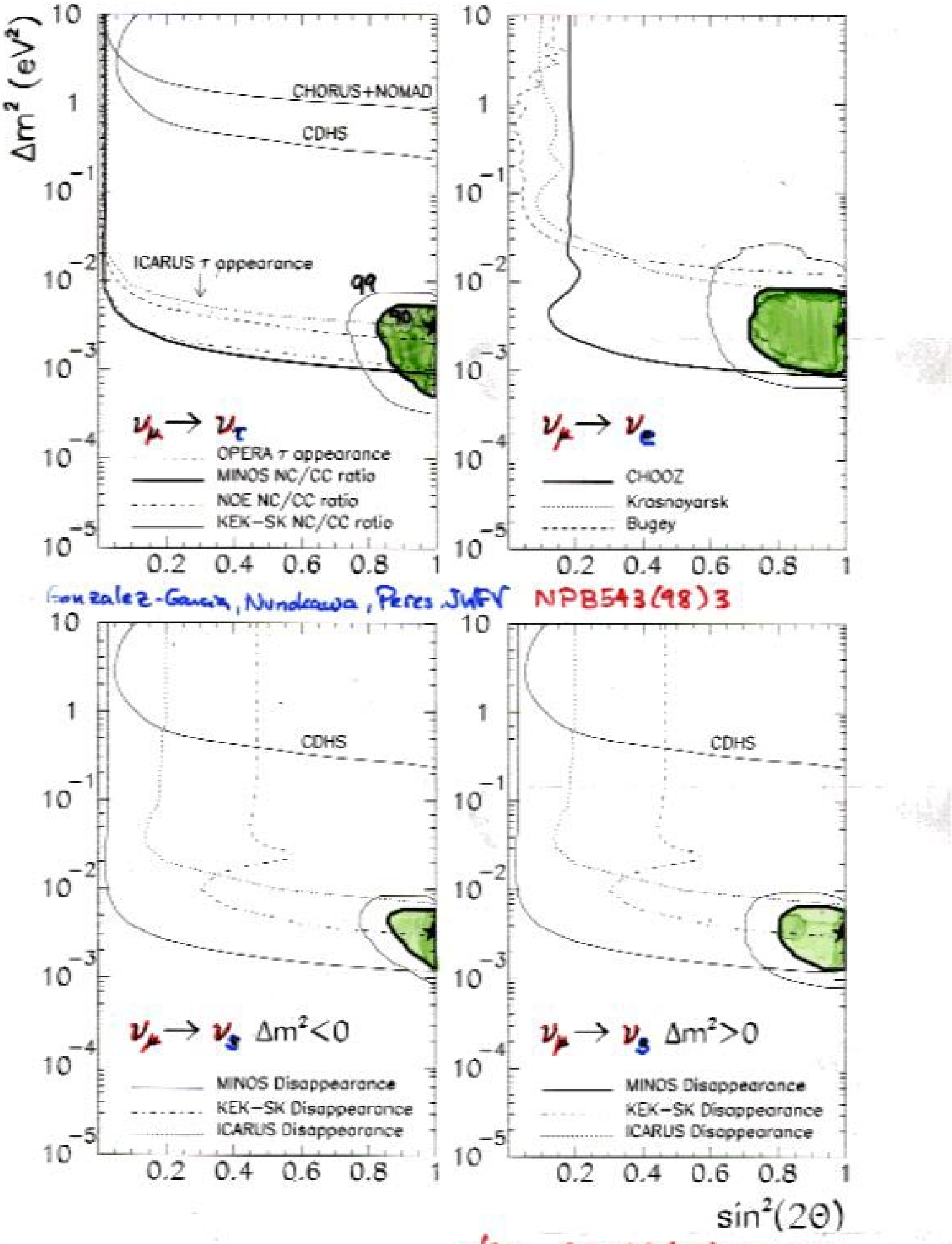
$$P(L) = 1 - \sin^2 2\theta \sin^2 \frac{\pi L}{L_\nu}$$

$$L_\nu \simeq \frac{4\pi E}{\Delta m^2} \simeq 2.5 \frac{\frac{E}{MeV}}{\frac{\Delta m^2}{eV^2}} m$$

$\sim 6 \times 10^6$ m

~ 6000 km $\sim$ Earth radius

535a



also PRD58(98)033004

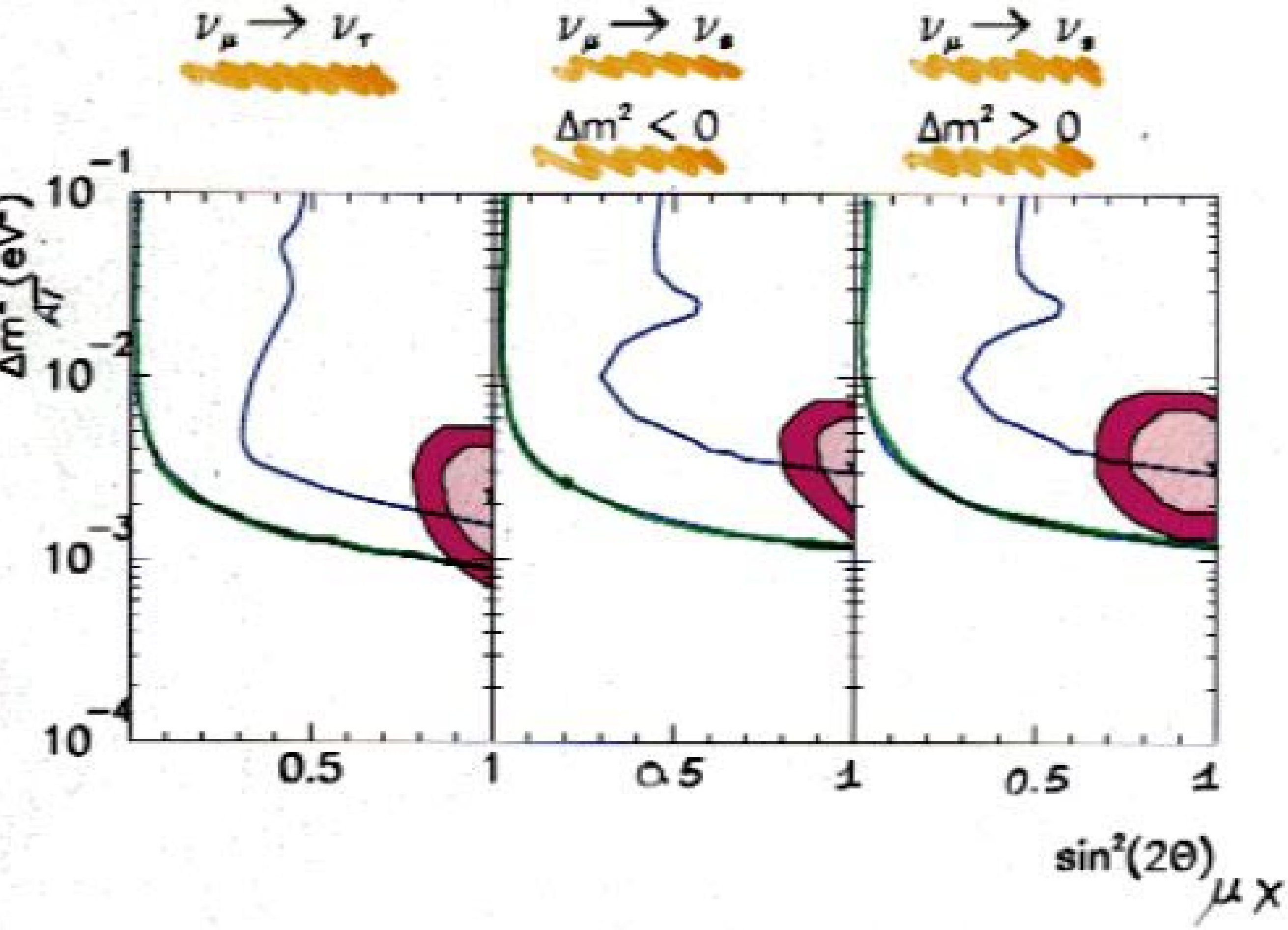
N Fornengo, MCG-G & J Valle work in progress

All SK combined (700 days)

sub-GeV + MultiGeV + stopping-μ + throughgoing μ

$\chi^2_{min}(\nu_\mu \to \nu_\tau) = 16/33$ d.o.f

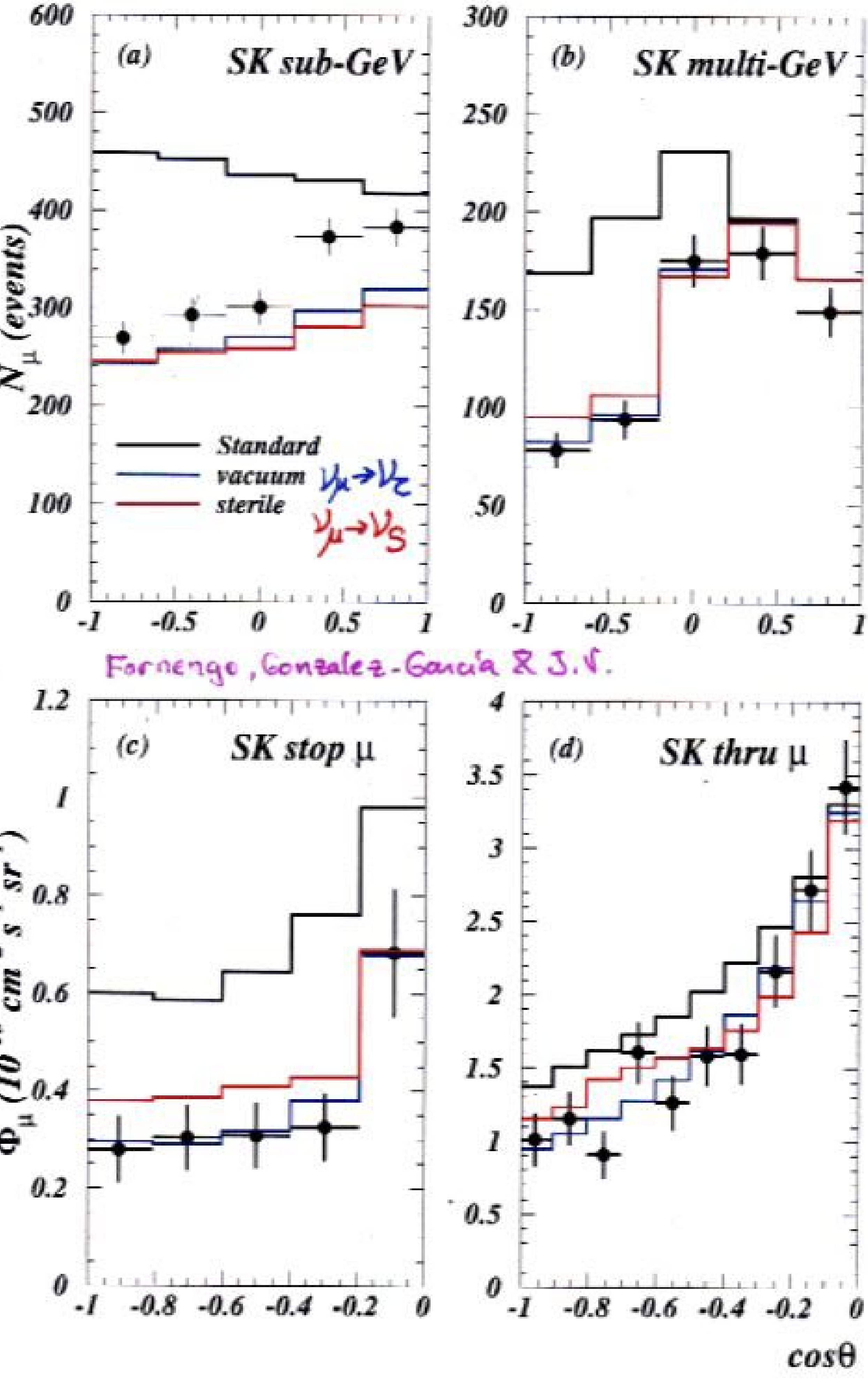
$\chi^2_{min}(\nu_\mu \to \nu_s) = 25/33$ d.o.f



Long baseline — K2K

— MINOS

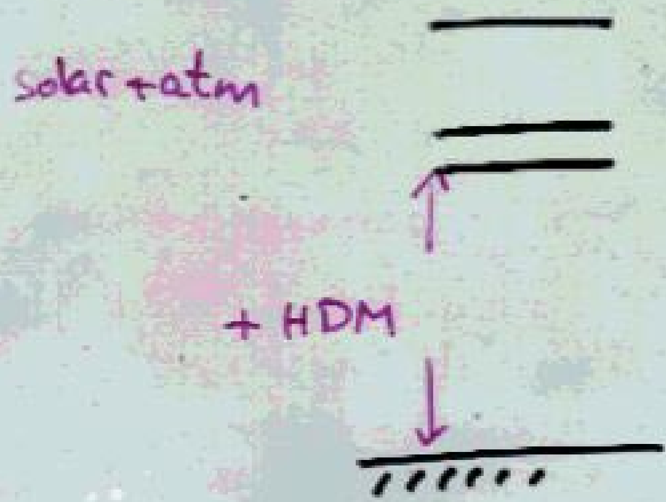
Atm 99 global Fit



Reconciling the anomalies

3ν-hierarchical & Quasi-degenerate

- **scales:** $\Delta m_{at}^2 \gg \Delta m_{\odot}^2$



simplest seesaw

+

rev seesaw

- Caldwell - Mohap.
- Ioannisian, J.V. PLB 332 (94) 93

.....

naturalness (Ellis, Lola) doesnot pose a real problem (Ma, Casas et al)
especially for relevant case where cancellation between opposite CP ν's take place in ββ0ν

- **angles:** $\theta_{at} \approx 45°$ $\theta_{\odot}$ may also be close to 45°

in general no prediction w/o adhoc texture/sym. assumptions

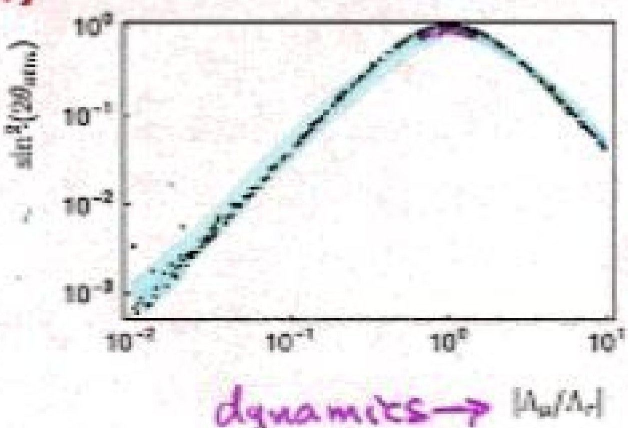
m_ν & θ_ν from R̸SUSY $P = P_{MSSM} + \epsilon L H$

⇓

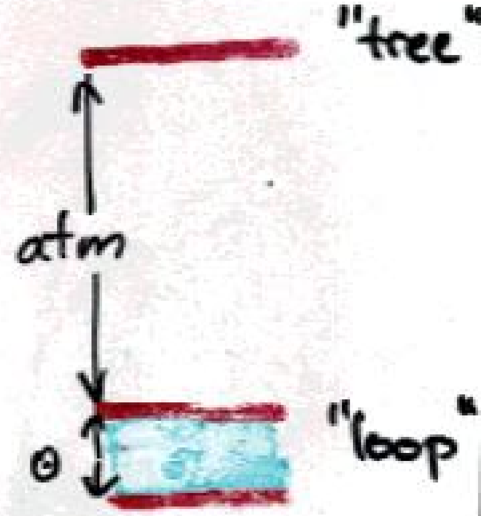
4 predictions mod/SUSY

Reconciling ⊙ + atm

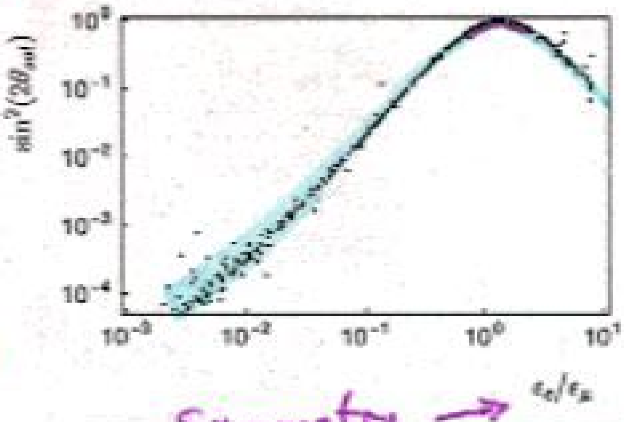
θ_{atm}



scales



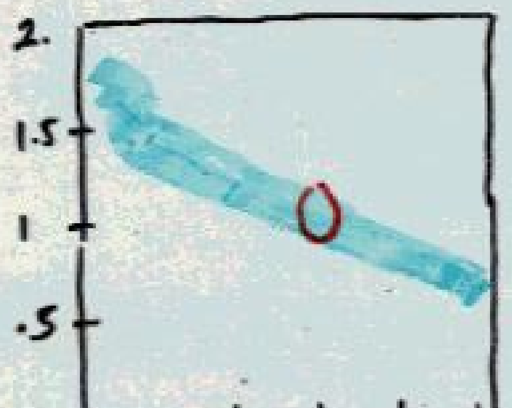
$\theta_\odot$



$\theta_{at} \simeq 45° \simeq \theta_\odot$

$\Delta m^2_{at} >> \Delta m^2_\odot$

- R̸p observable @ accelerators



$$R = \frac{\Gamma(LSP \to \mu\, q'\bar{q})}{\Gamma(LSP \to \tau\, q'\bar{q})} \simeq 1$$

- Test of Bimaximality !

Diaz, Romão & JWV. NPB 524 (98) 23

Romão, Hirsch, Porod, Diaz, J.W.F.V. hep-ph/9907499

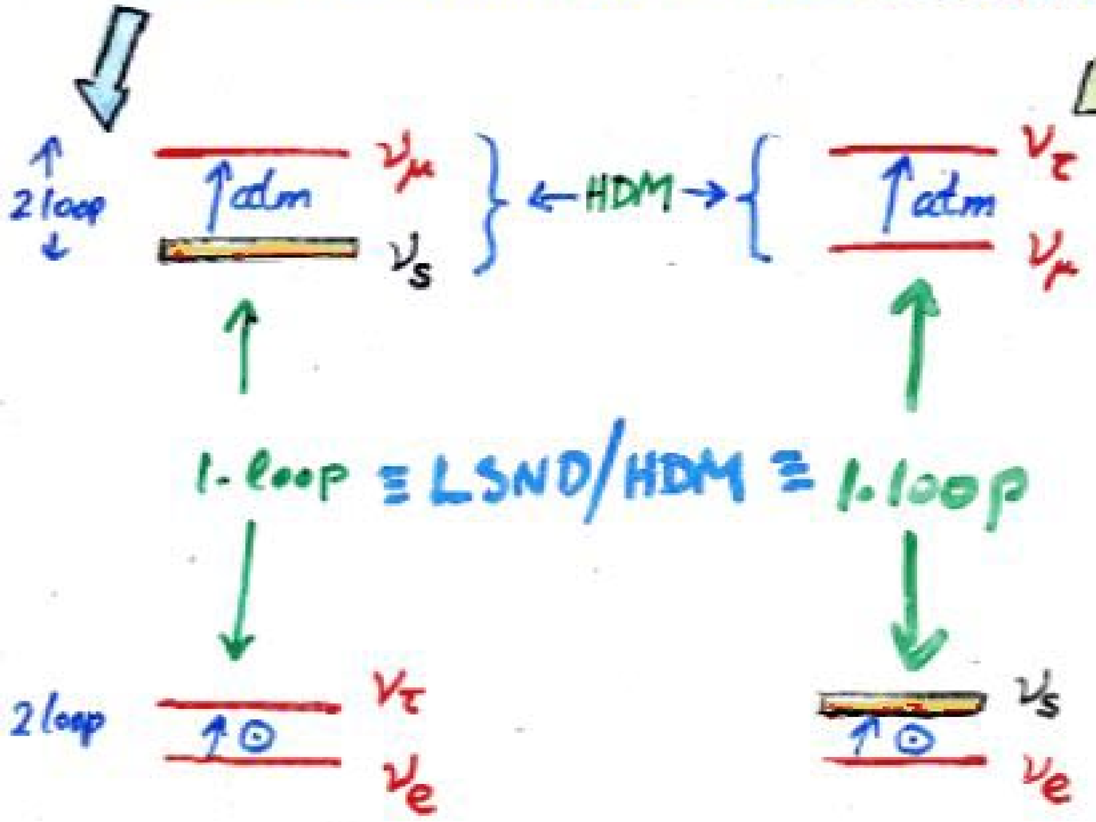
RECONCILING

⊙, atm & LSND/HDM

◆ LSND ➡ 4th ν ➡ (LEP/SLC) ν_s S = STERILE

Peltoniemi, Tommasini & J.V. ■ PLB298(93)383 ■ CERNTH 6624-92

Peltoniemi & J.V. NPB406(93)409



⇨ can be distinguished @ NC-sensitive expts e.g. SNO (solar) & SKam (atm + solar)

⇨ Global L-number protects ν_s

⇨ L violation generates ⊙ & atm splittings with $\sin^2 2\theta_{atm} = 1$

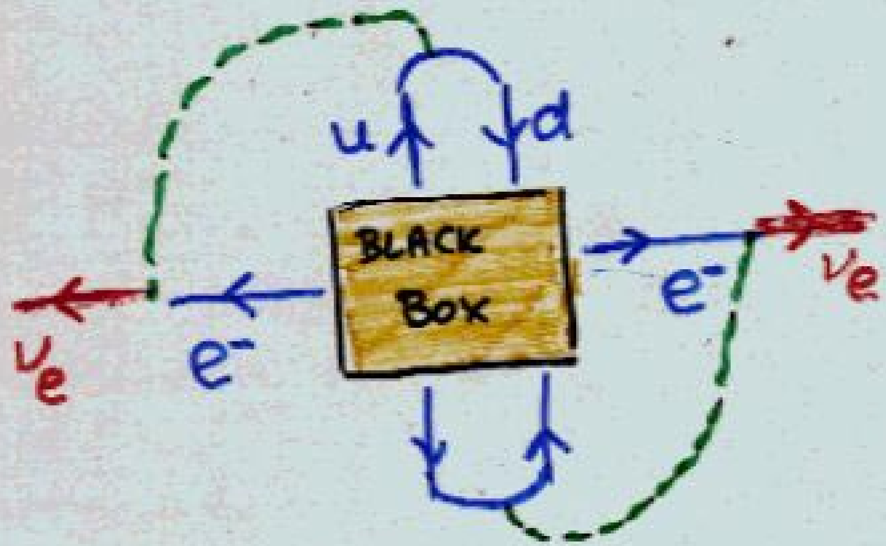
do present underg. data

really $\Rightarrow$ $m_\nu \neq 0$?

$\theta_\nu \neq 0$?

LNV → m_ν^{Maj}

conceptual importance of $\beta\beta_{0\nu}$: whatever the mechanism inducing $\beta\beta_{0\nu}$ it leads to m_ν^{Maj} in a gauge theory



Schechter & J.V. PRD25 (82) 2951

LFV ↛ m_ν

lepton flavor violation with strictly massless ν's has both conceptual as well as practical interest, since it can be large

$\mu \to e\gamma$
$\tau \to \ell\gamma$
μ-e conversion

[Prog. Part. Nucl. Phys. 26 (91) 91-171]

may lead to massless ν-oscillation !

Massless ν- oscil.

ν- mixing without mass ↓

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\tau\end{pmatrix} \simeq \frac{\sqrt{2}G_F\rho}{m_N}\begin{pmatrix} Y_e-\frac{Y_n}{2}(1-h_e^2) & \eta(Y_n-Y_e)sc \\ \text{sym} & -\frac{Y_n}{2}(1-h_\tau^2)\end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\tau\end{pmatrix}$$

Resonant ν_e- conversion if $Y_e = \eta Y_n$

PLB199(87)432

where

- $\eta = \frac{h_\tau^2 - h_e^2}{2} \neq 0$ breaks univ.

& makes $\langle \nu_e | \nu_\tau \rangle \sim sc\Delta h \neq 0$

- ν_e-ν_τ resonance may happen in SN @ $r \gtrsim 10$ km ($Y_e \ll Y_n$)
- E-independent
- converts both ν's & $\bar{\nu}$'s

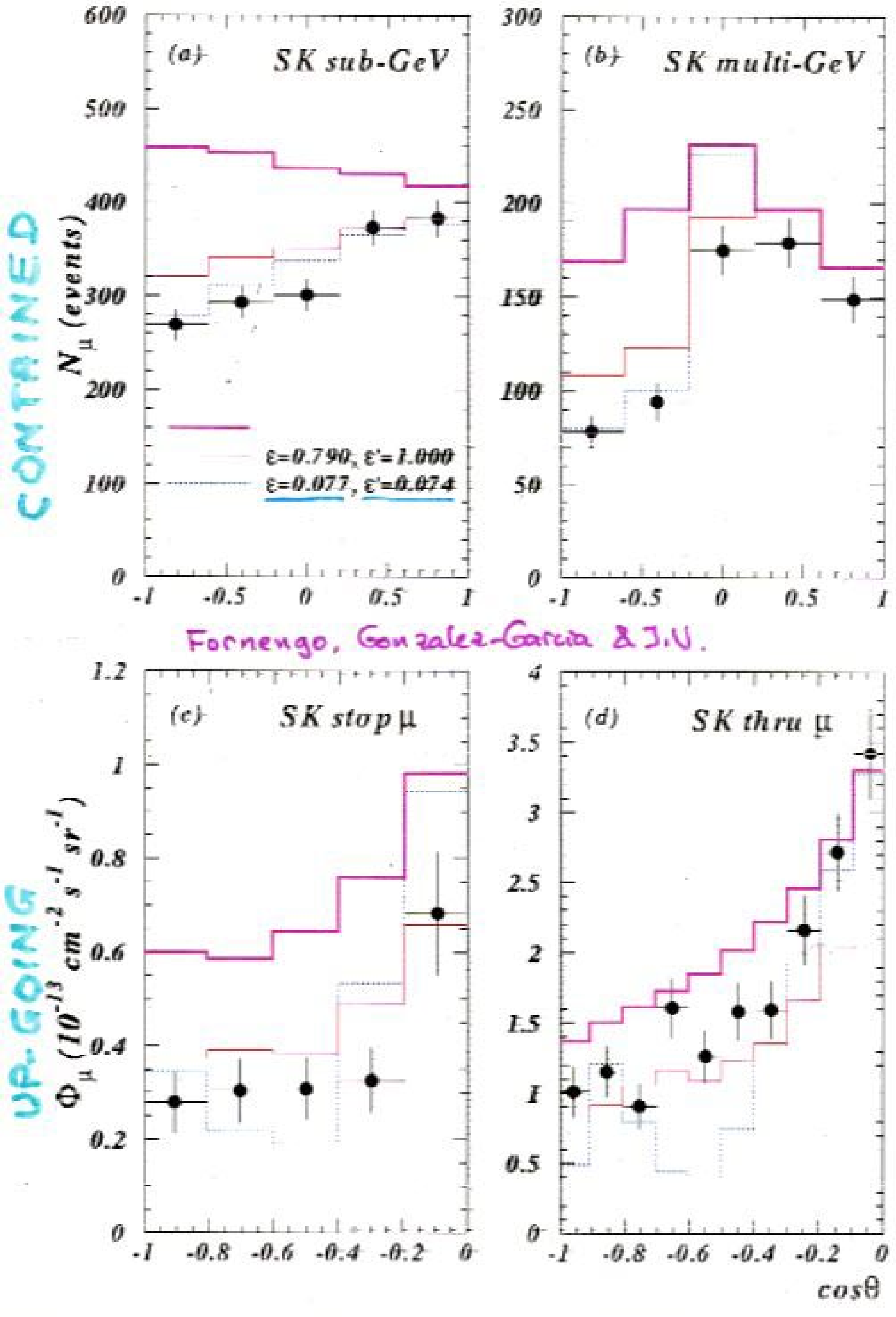
possible implications

⇨ SN - physics (ν_e-ν_τ) Nunokawa, Qian, Rossi & JV PRD54 (96) 4356

⇨ pulsars (ν_e-ν_τ) Nunokawa, Grasso & J.V. PRL81 (98) 2412

⇨ atm ν (ν_μ-ν_τ) Gonzalez-Garcia et al hep-ph 9809531 = PRL82 (99) 3202

Atm 99 FC Fit hep-ph/9906539



SUMMARY

- ν's should be massive & majorana with masses anywhere up to kinematical lab. bounds
- all other bounds (∋ cosmo : BBN + ρ_c) are model-dependent
- atm + solar ⇒ ν-conversions take place but
  ↳ ν_{up} - ⇏ m_ν , θ_ν
- recent MSW fit puts LMA on better footing
  - Role of seasonality? Bimaximality?
- IF ⊙, atm & DM true

MeV ν_τ + LSND

or

NPB490(95)647

late ν_τ decay delays Teq

ν_τ, ν_μ, ν_e } ≃ 1.5eV

HCDM

ττCDM

ν_s, ν_μ — ν_τ, ν_r

ββ0ν

zero

$\nu_e . \nu_\mu . \nu_s$

ν_τ, ν_e — ν_s, ν_e