LSND, MiniBooNE, and sterile neutrinos

Moriond EW, La Thuile, 6 Mar 2008

Thomas Schwetz-Mangold

CERN

Outline

- Brief introduction
- Short-baseline data and sterile neutrino oscillation

  4-neutrinos, 5-neutrinos, 6-neutrinos

  M. Maltoni, T. Schwetz, 0705.0107 [PRD]
- Comments on exotic solutions

  non-standard energy dependence

  T. Schwetz, 0710.2985 [JHEP]
- Summary and outlook

The LSND signal

evidence for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations

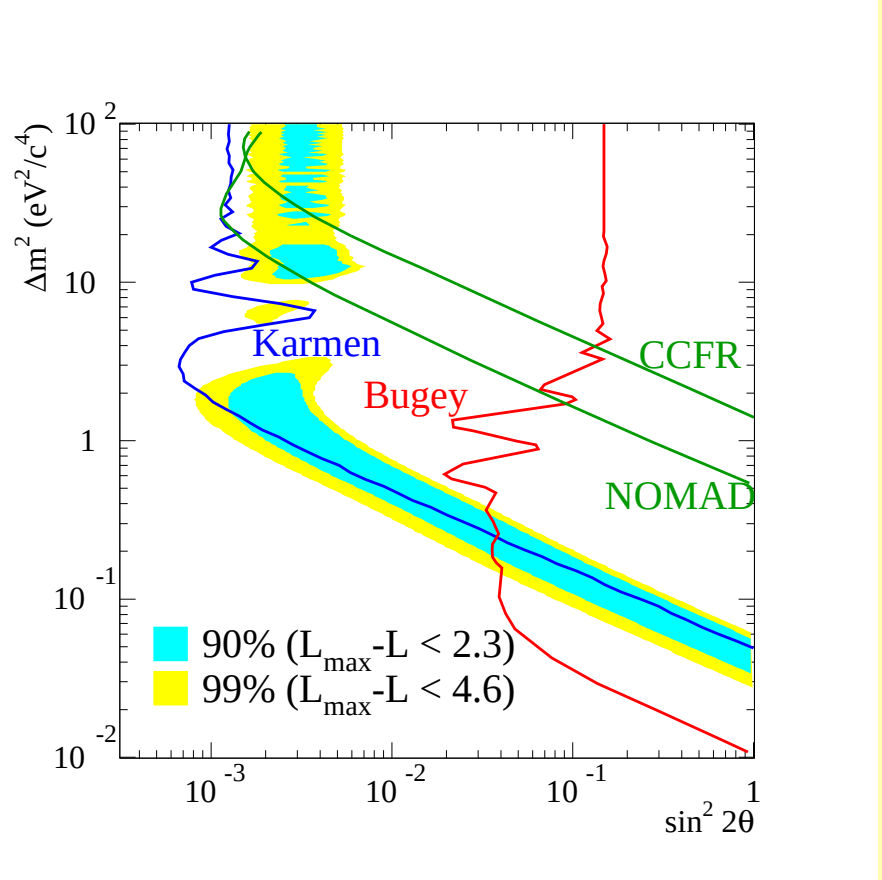
$87.9 \pm 22.4 \pm 6.0$ excess events

$P = (0.264 \pm 0.067 \pm 0.045)\%$

$\sim 3.3\sigma$ away from zero

the problem:

$\Delta m^2 \sim$ eV^2 not consistent with solar (8×10^{-5}) and atmospheric (2.5×10^{-3}) mass splittings for three neutrinos!

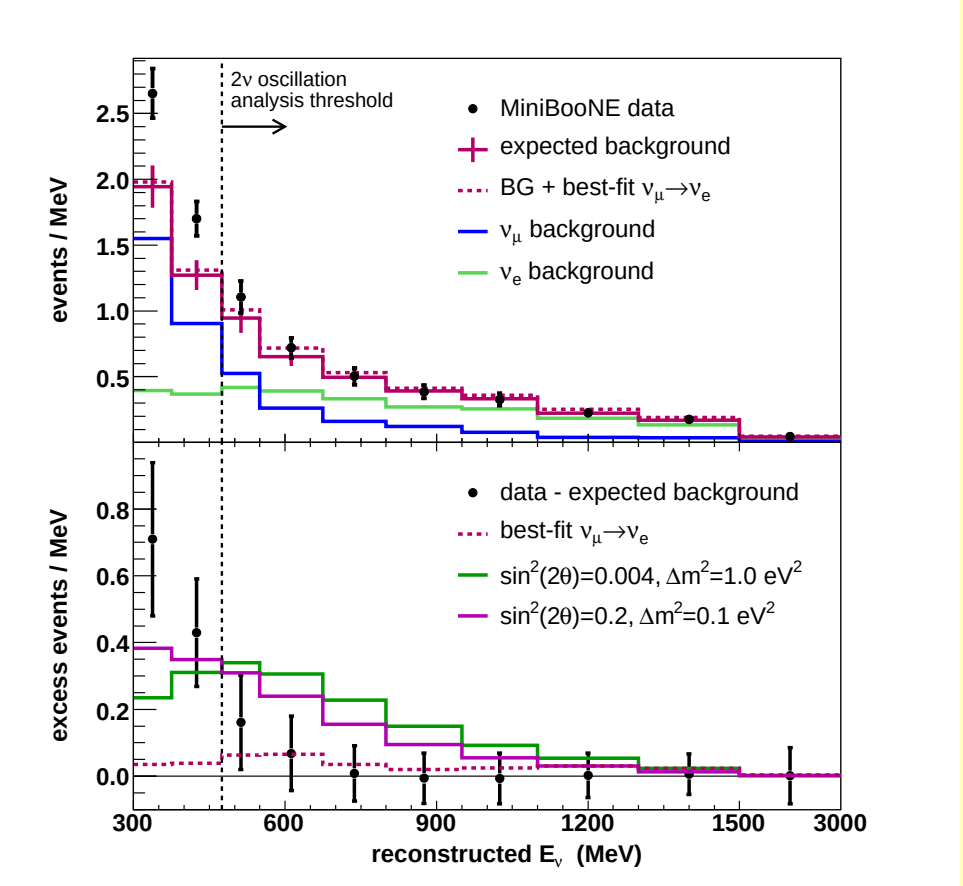


MiniBooNE results

obs. events minus background:

$475 < E_\nu^{\mathrm{QE}} < 1250\,\mathrm{MeV}$:
$22 \pm 19 \pm 35$ events
(consistent with zero)

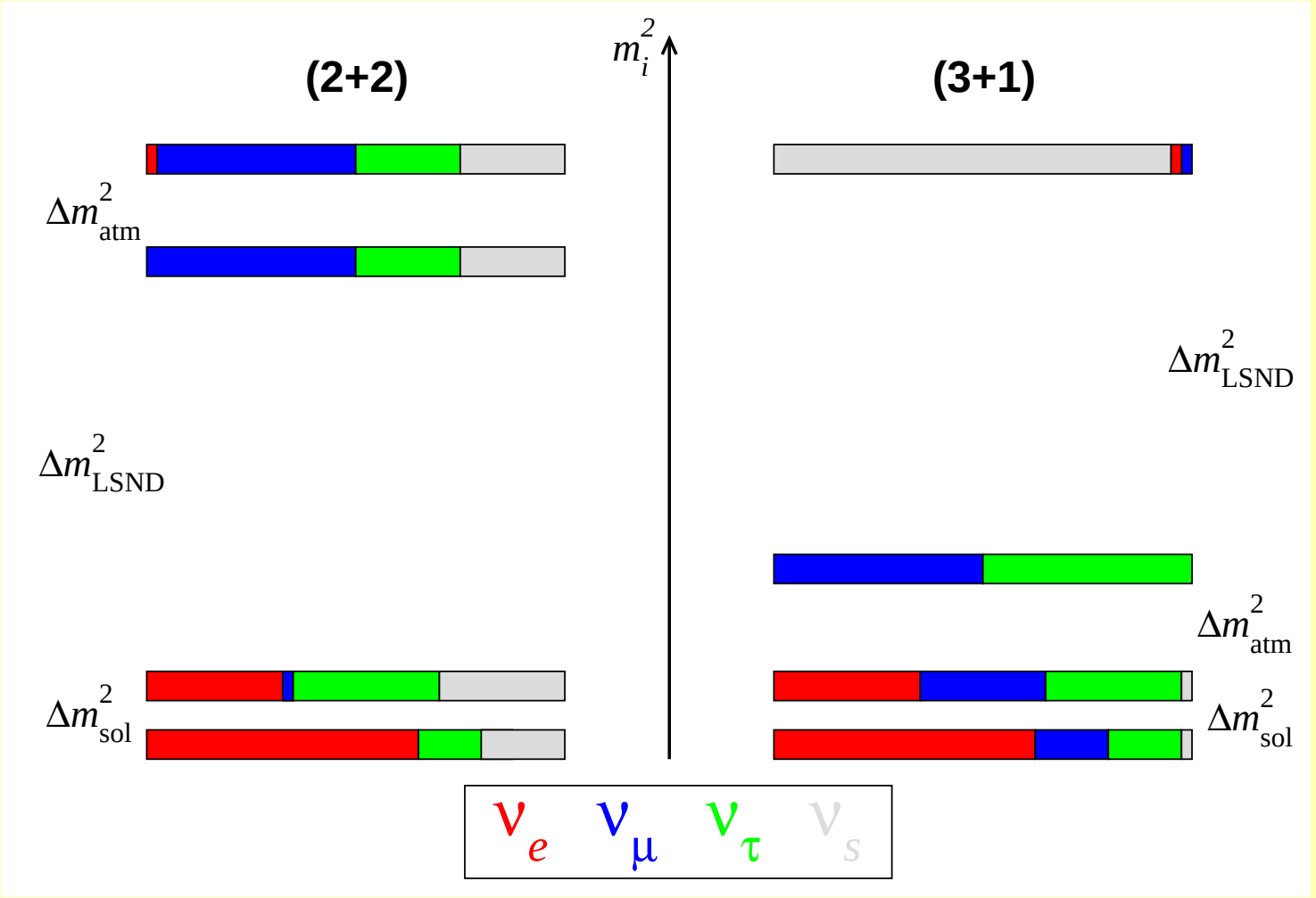
$300 < E_\nu^{\mathrm{QE}} < 475\,\mathrm{MeV}$:
$96 \pm 17 \pm 20$ events
(excess at 3.6σ)



4-neutrino oscillations?

Adding a sterile neutrino

4-neutrino mass schemes:



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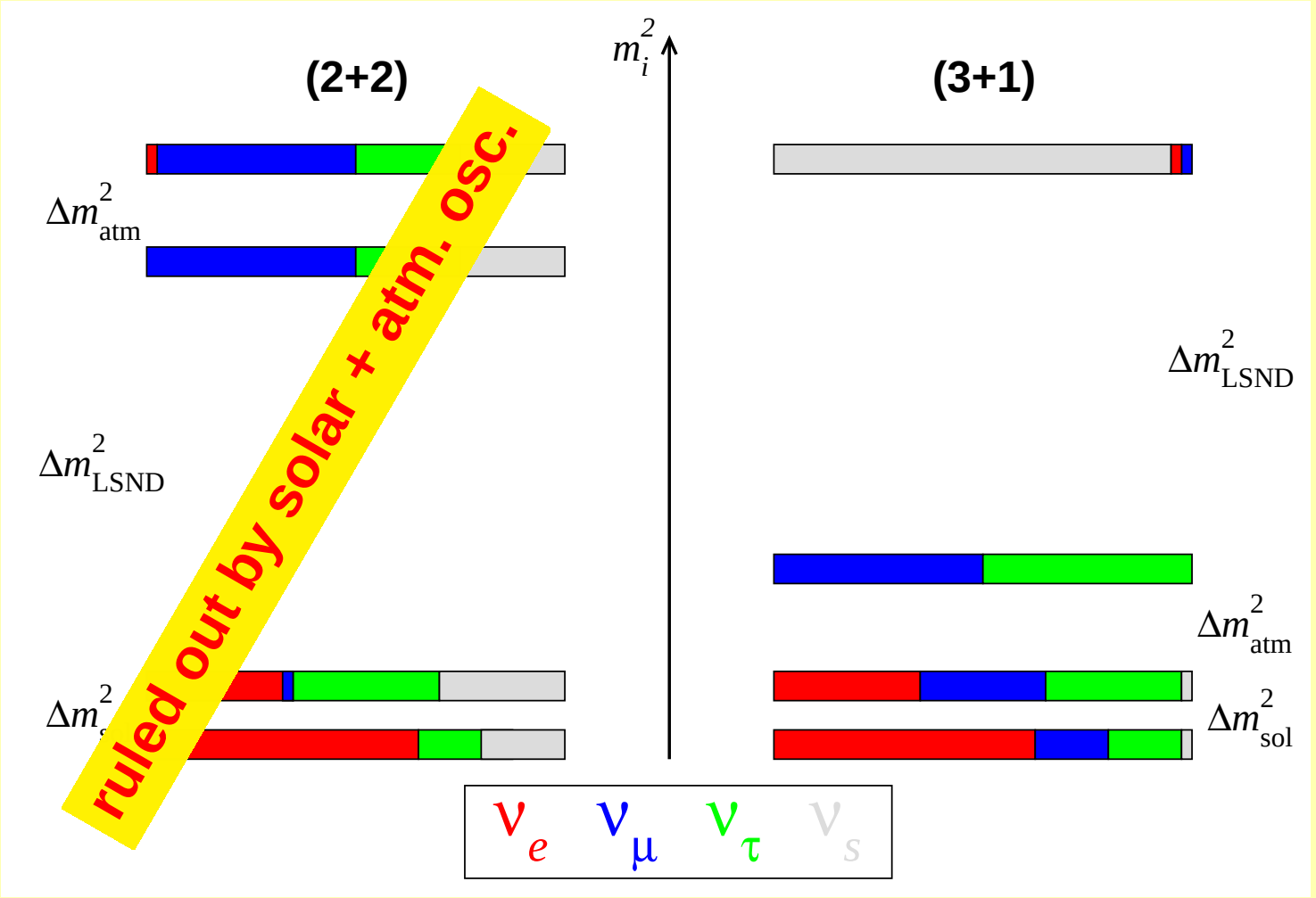

MB vs LSND in (3+1)

In (3+1) schemes the SBL appearance probability is effectively 2-ν oscillations:

$$P_{\mu e} = \sin^2 2\theta_{\rm SBL} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

with

$$\sin^2 2\theta_{\rm SBL} = 4|U_{e4}|^2|U_{\mu 4}|^2$$

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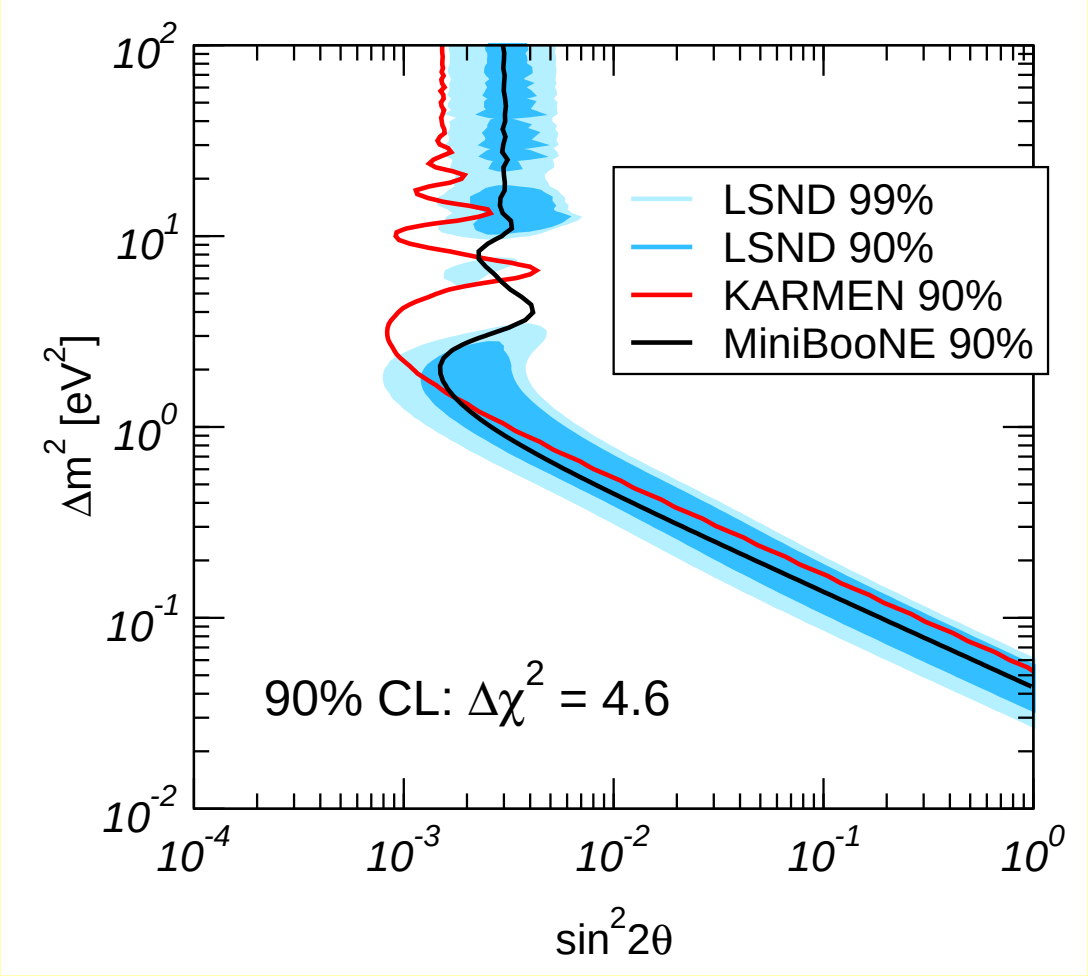
LSND / MiniBooNE (in)consistency is the same as in the 2-flavour case

The MiniBooNE 2-neutrino limit

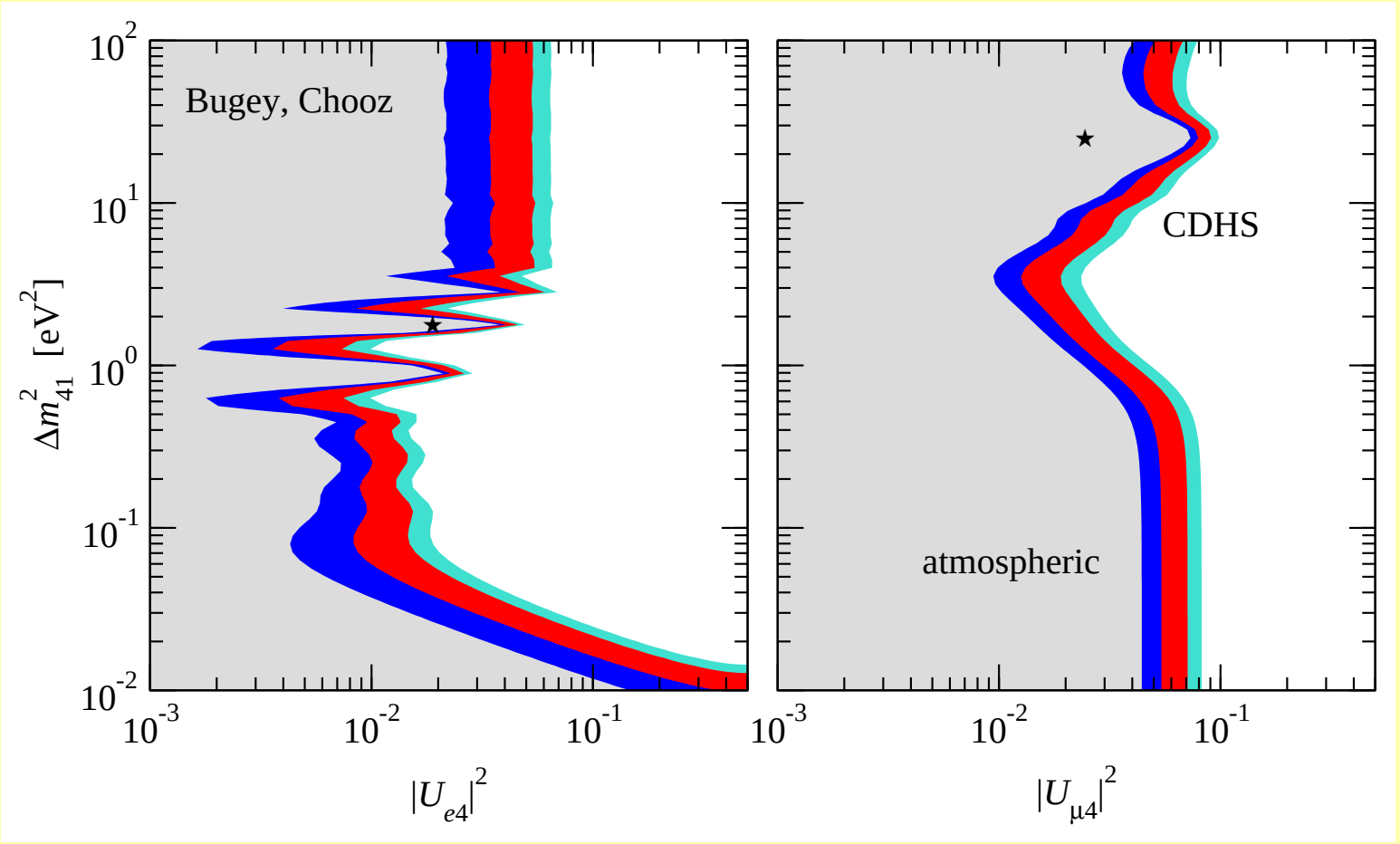


In the 2-neutrino framework MiniBooNE and LSND are incompatible at the 98% CL Aguilar-Arevalo et al., PRL08

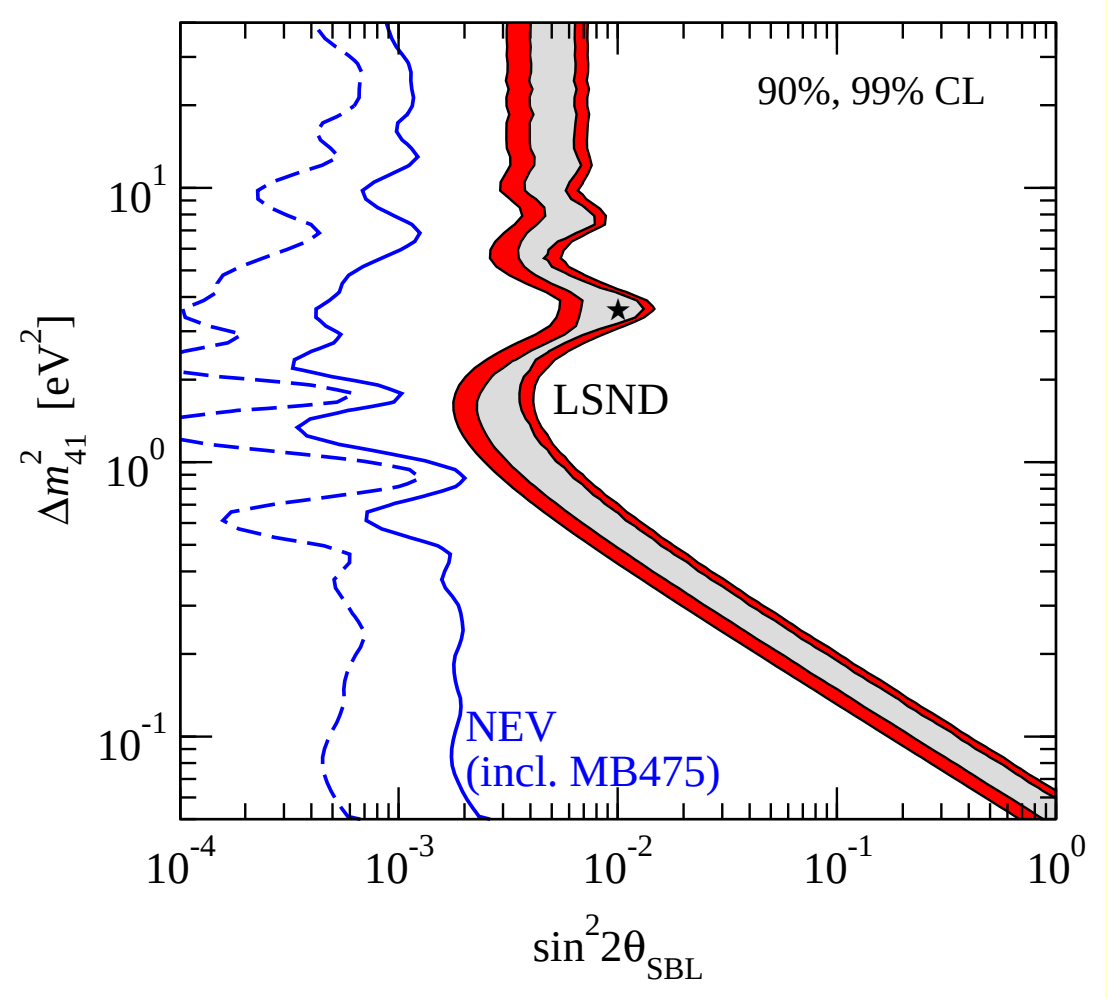
Appearance vs disappearance in (3+1)

appearance amplitude $\sin^2 2\theta_{\rm SBL} = 4|U_{e4}|^2|U_{\mu 4}|^2$

$\Leftrightarrow$ disapp. exps. constrain $|U_{e4}|^2$ and $|U_{\mu 4}|^2$



(3+1) global



before MB:

$\chi^2_{\rm PG} = 20.9\,(2\,{\rm dof})$

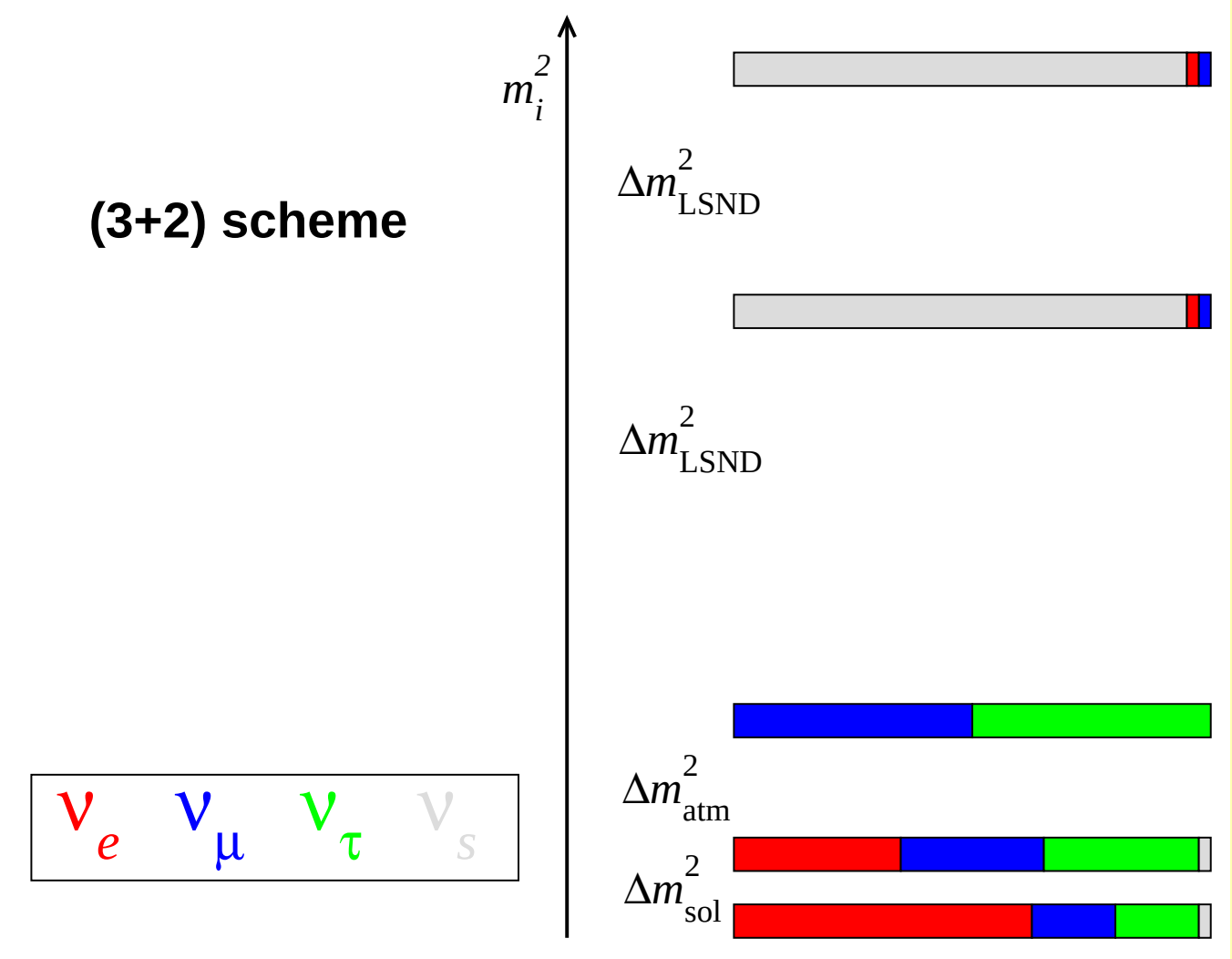
MB incl.:

$\chi^2_{\rm PG} = 24.7\,(2\,{\rm dof})$

disagreement at about 4σ

More sterile neutrinos?

5-neutrino oscillations



Sorel, Conrad, Shaevitz, hep-ph/0305255

(3+2) appearance probability

$$
\begin{aligned}
P_{\nu_\mu \to \nu_e} &= 4\,|U_{e4}|^2 |U_{\mu 4}|^2 \sin^2\phi_{41} \\
&+ 4\,|U_{e5}|^2 |U_{\mu 5}|^2 \sin^2\phi_{51} \\
&+ 8\,|U_{e4}U_{\mu 4}U_{e5}U_{\mu 5}| \sin\phi_{41}\sin\phi_{51}\cos(\phi_{54} - \delta)
\end{aligned}
$$

with the definitions

$$
\phi_{ij} \equiv \frac{\Delta m^2_{ij} L}{4E}\,, \qquad \delta \equiv \arg\left(U^*_{e4} U_{\mu 4} U_{e5} U^*_{\mu 5}\right)\,.
$$

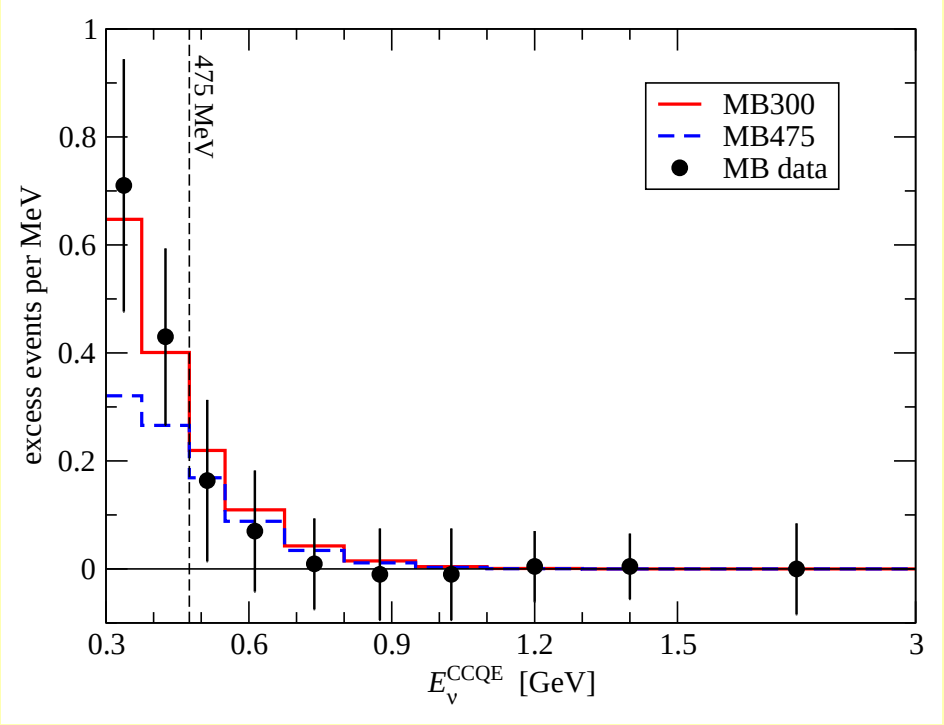
(3+2) osc. include the possibility of CP violation!

remember: MiniBooNE: neutrinos, LSND: anti-neutrinos

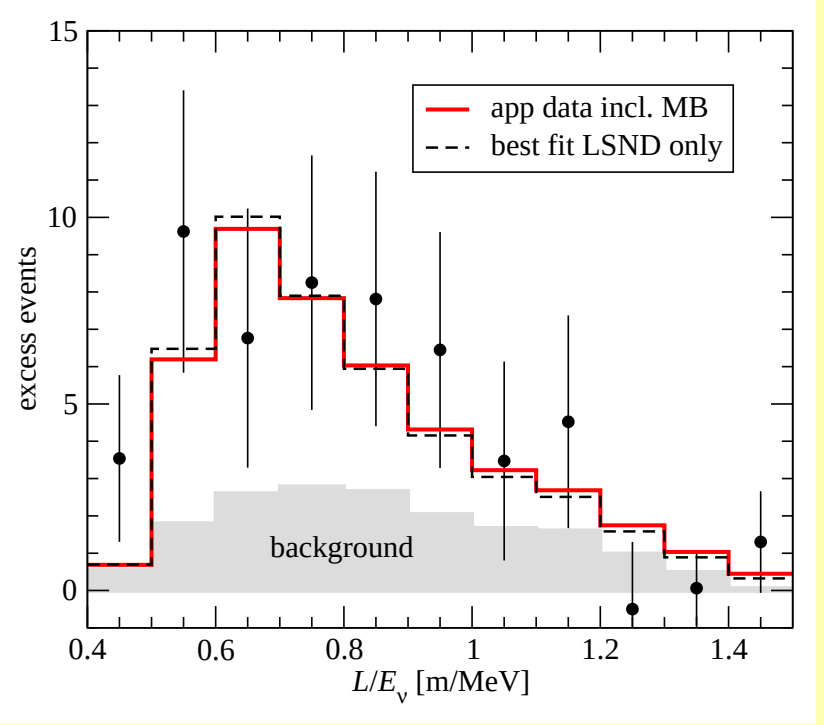
(3+2) appearance data

best fit point spectra:

MiniBooNE



LSND



Perfect fit to appearance data:

w/o MB low energy excess: $\chi^2_{\rm min} = 16.9/(29-5)$

with MB low energy excess: $\chi^2_{\rm min} = 18.5/(31-5)$

(3+2) disappearance data

what about the disappearance data?

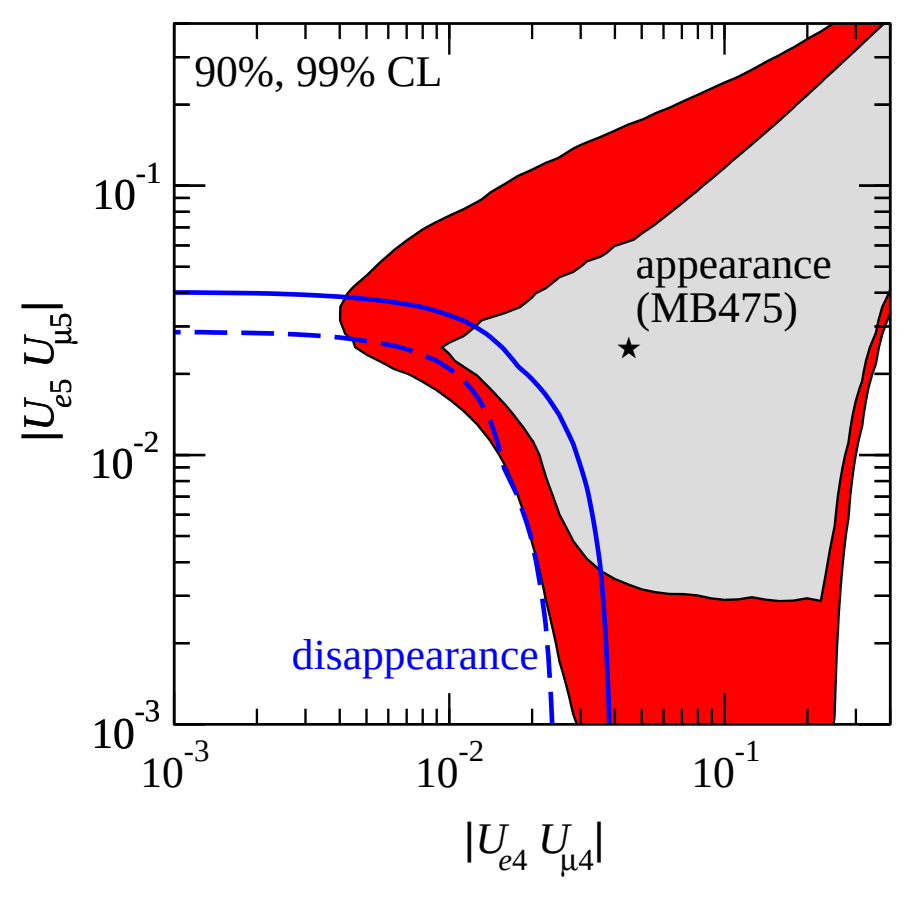
$$
\begin{aligned}
P_{\nu_\alpha \to \nu_\alpha} &= 1 - 4 \left(1 - \sum_{i=4,5} |U_{\alpha i}|^2 \right) \sum_{i=4,5} |U_{\alpha i}|^2 \sin^2 \phi_{i1} \\
&- 4 \, |U_{\alpha 4}|^2 |U_{\alpha 5}|^2 \, \sin^2 \phi_{54}
\end{aligned}
$$

$\Rightarrow$ bound $|U_{ei}|$ and $|U_{\mu i}|$ $(i = 4, 5)$, similar as in (3+1)

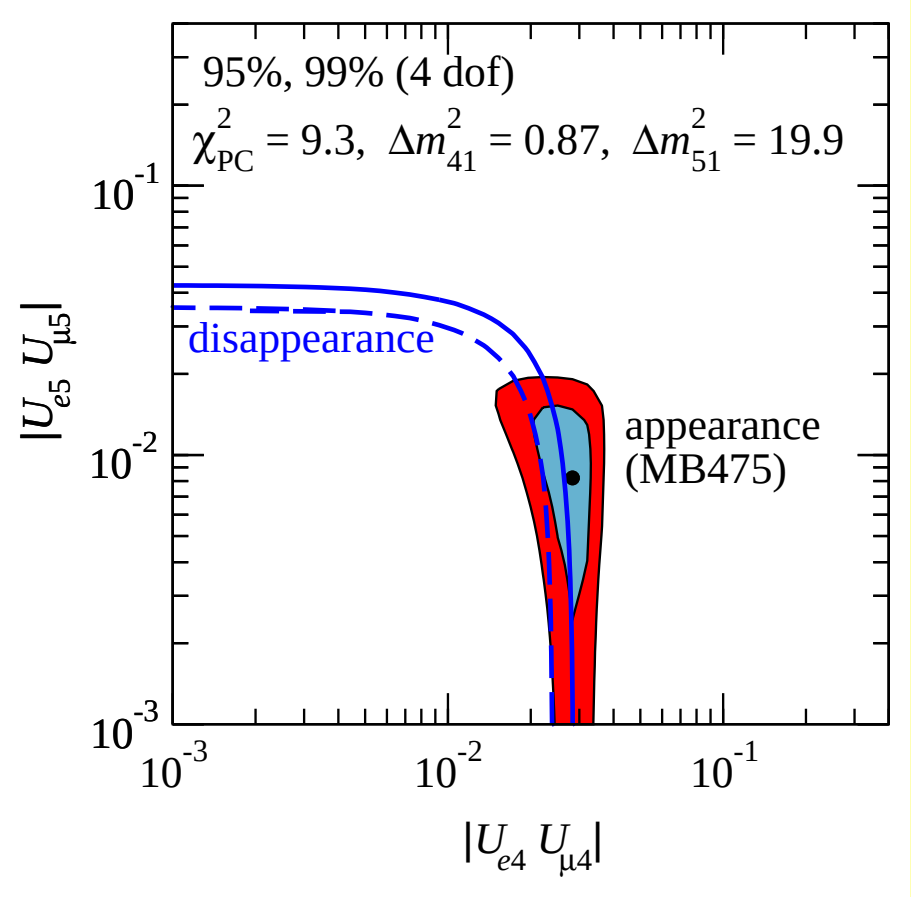
to be reconciled with appearance amplitudes $|U_{ei} U_{\mu i}|$

(3+2) app vs disap

projection



section



(3+2) global

testing consistency of disappearance and appearance data:

$$\chi^2_{\rm PG} = 17.2\,(4\,{\rm dof}) \qquad {\rm PG} = 0.18\%$$

(without MB: $\chi^2_{\rm PG} = 17.5$)

inconsistency at about 3.1σ

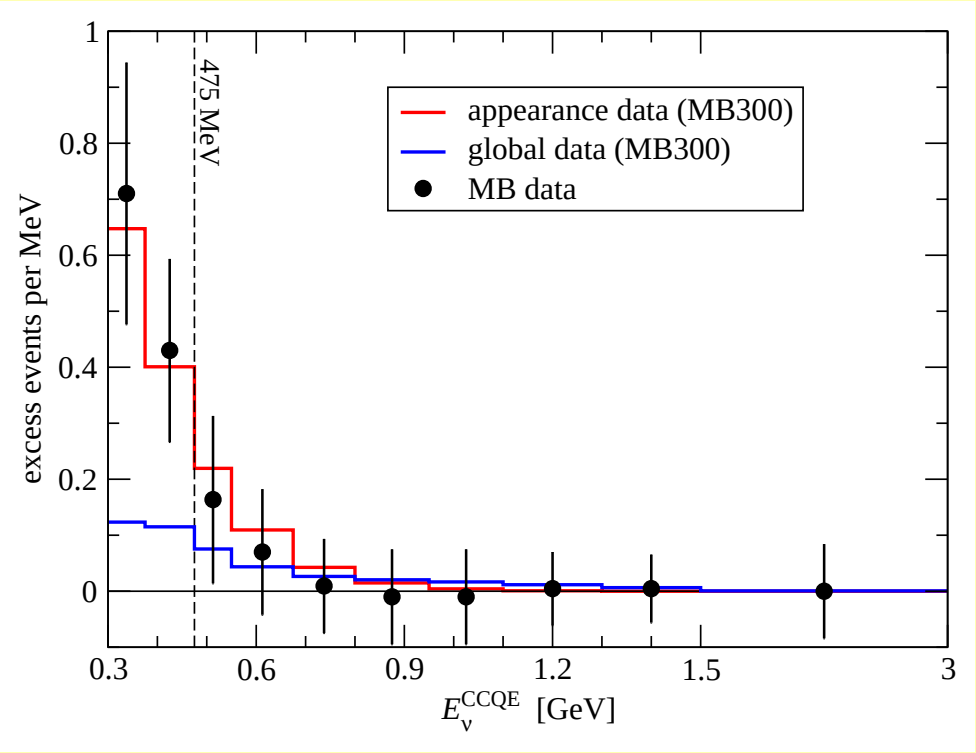
parameters in common $|U_{e4}U_{\mu 4}|, |U_{e5}U_{\mu 5}|, \Delta m^2_{41}, \Delta m^2_{51}$

best fit: $\Delta m^2_{41} = 0.9$ eV^2, $\Delta m^2_{51} = 6.5$ eV^2, $\chi^2_{\rm min} = 94.5/(107-7)$

$\chi^2_{\rm min,\ global\,(3+1)} - \chi^2_{\rm min,\ global\,(3+2)} = 6.1/4$ dof (81% CL)

the low energy MB excess in the (3+2) fit

the MB low energy excess is not reproduced at the global best fit point:



$$\chi^2_{\rm MB300} = 104.4/(109-7)$$

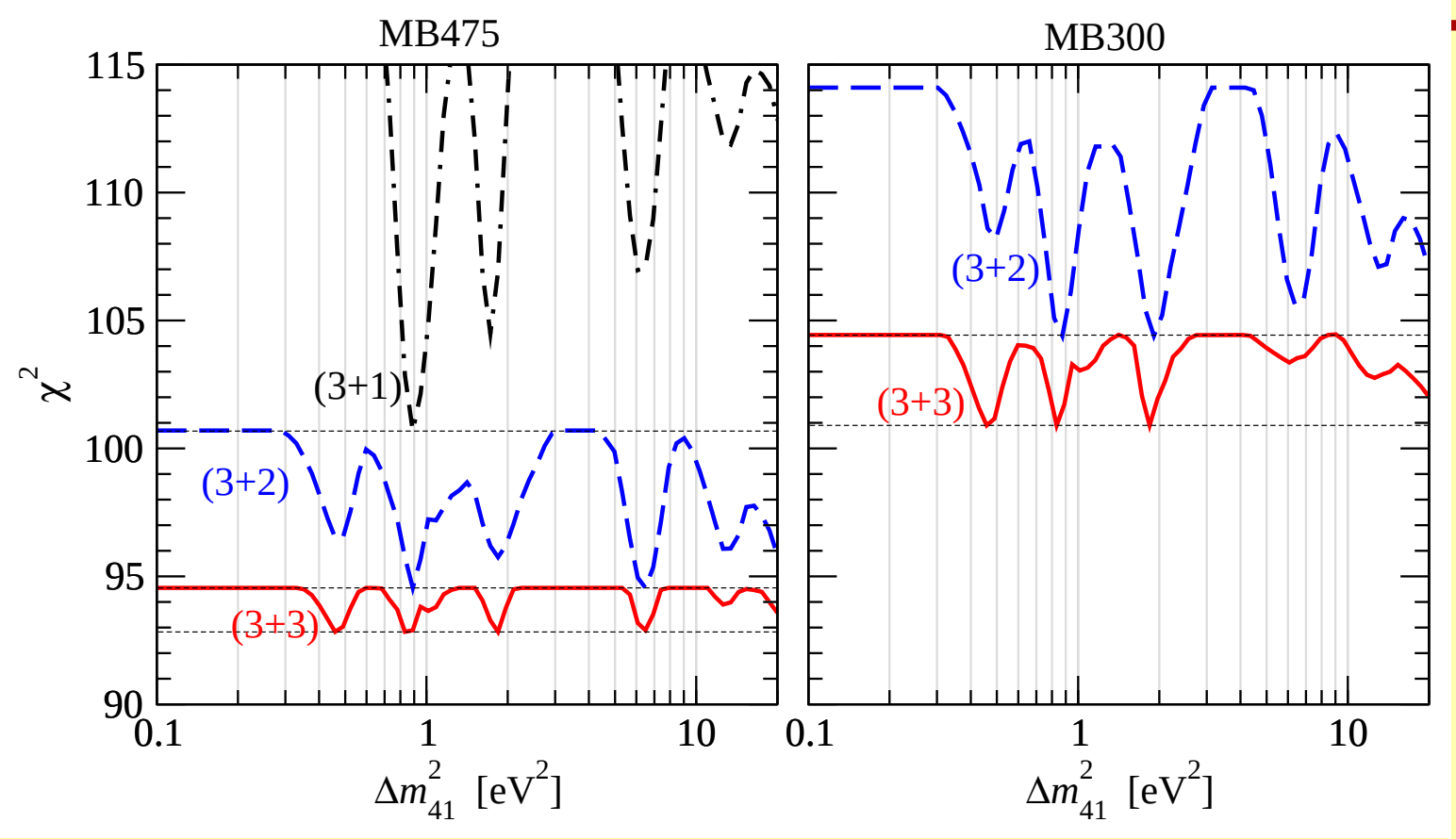
$$\chi^2_{\rm MB475} = 94.5/(107-7)$$

$$\chi^2_{\rm PG} = 25.1/4$$

$$\mathrm{PG} = 4.8 \times 10^{-5}\ (4\sigma)$$

adding another sterile . . .

(3+3) . . . does not help



	Δm^2_{41}	Δm^2_{51}	Δm^2_{61}	$\chi^2_{\rm min}$	$\chi^2_{(3+2)} - \chi^2_{(3+3)}$	CL
MB475	0.46	0.83	1.84	92.8	$1.7/4$	20%
MB300	0.46	0.83	1.84	100.9	$3.5/4$	52%

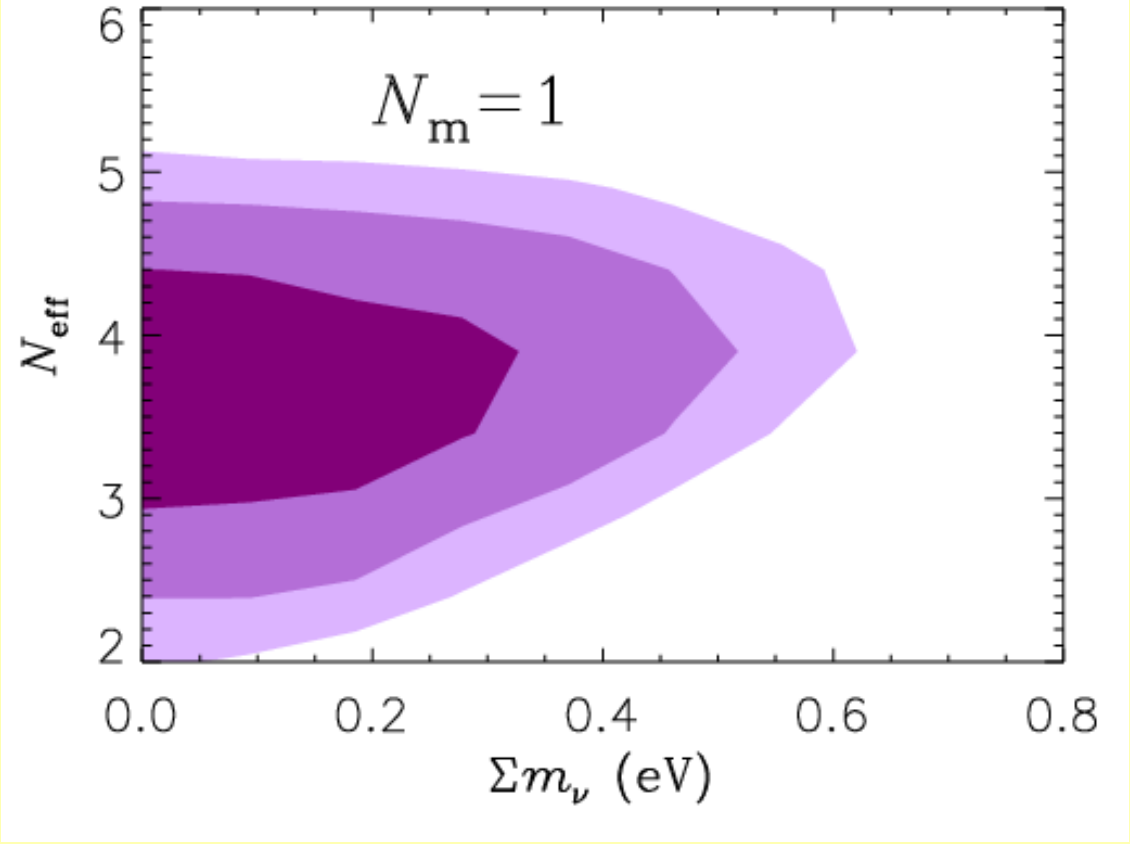
All these sterile neutrino schemes

have problems with cosmology

- sterile states contribute to the relativistic degrees of freedom (CMB, BBN)
- conflict with bound on the sum of neutrino masses from various cosmological data sets (LSS)

Cosmology

SN Ia, LSS (2dF, SDSS), BAO, CMB (WMAP, BOOMERANG)



68%, 95%, 99% CL

Hannestad, Raffelt, astro-ph/0607101

More ’exotic’ proposals

- 3-neutrinos and CPT violation Murayama, Yanagida 01; Barenboim, Borissov, Lykken 02; Gonzalez-Garcia, Maltoni, Schwetz 03

- 4-neutrinos and CPT violation Barger, Marfatia, Whisnant 03
- Exotic muon-decay Babu, Pakvasa 02
- CPT viol. quantum decoherence Barenboim, Mavromatos 04
- Lorentz violation
  Kostelecky, Mews, 04; Gouvea, Grossman, 06; Katori, Kostelecky, Tayloe, 06
- mass varying neutrinos
  Kaplan, Nelson, Weiner 04; Zurek 04; Barger, Marfatia, Whisnant 05
- shortcuts of sterile neutrinos in extra dimensions
  Paes, Pakvasa, Weiler 05
- 1 decaying sterile neutrino Palomares-Riuz, Pascoli, Schwetz 05
- 2 decaying sterile neutrinos with CPV
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- 3-neutrinos and CPT ... Yanagida 01; Barenboim, B... 02; Gonzalez-Garcia, Maltoni, Schwetz 03

KamLAND+atmospheric antineutrino data

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KamL+atmospheric?

An exotic sterile neutrino with energy dependent mass or mixing

TS, 0710.2985 [hep-ph]

Energy dependent sterile neutrino

Experiment	Channel	$\langle E_\nu \rangle$
Bugey	$\bar{\nu}_e \to \bar{\nu}_e$	4 MeV
Chooz	$\bar{\nu}_e \to \bar{\nu}_e$	4 MeV
Palo Verde	$\bar{\nu}_e \to \bar{\nu}_e$	4 MeV
LSND	$\bar{\nu}_\mu \to \bar{\nu}_e$	40 MeV
KARMEN	$\bar{\nu}_\mu \to \bar{\nu}_e$	40 MeV
MiniBooNE	$\nu_\mu \to \nu_e$	700 MeV
CDHS	$\nu_\mu \to \nu_\mu$	1 GeV
NOMAD	$\nu_\mu \to \nu_e$	50 GeV

e.g., assume a 4th neutrino with an energy dependent mass or mixing:

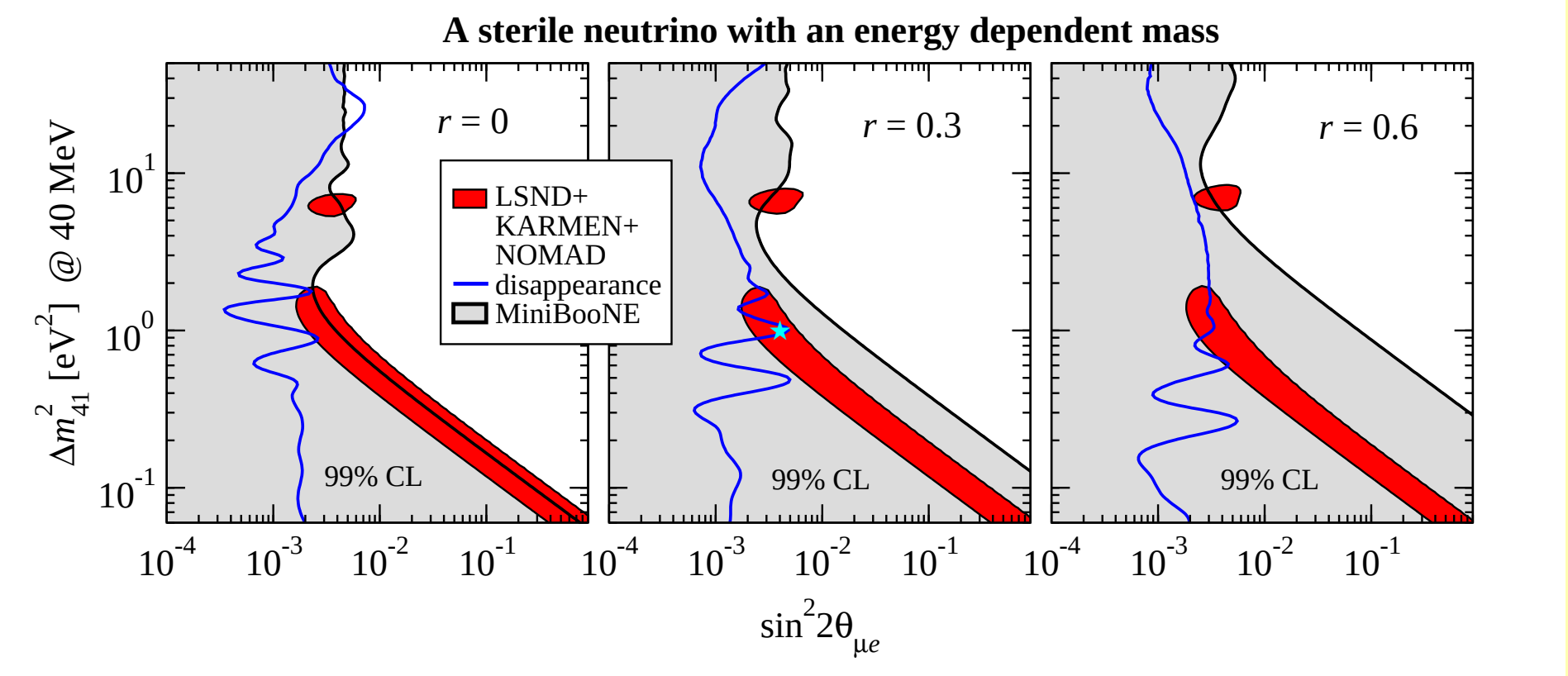
$$m_4^2 = m_*^2 \left(\frac{E_*}{E_\nu} \right)^r$$

or

$$|U_{\alpha 4}|^2 = |U_{\alpha 4}^*|^2 \left(\frac{E_*}{E_\nu} \right)^r$$

$(r \geq 0)$

Energy dependent sterile neutrino



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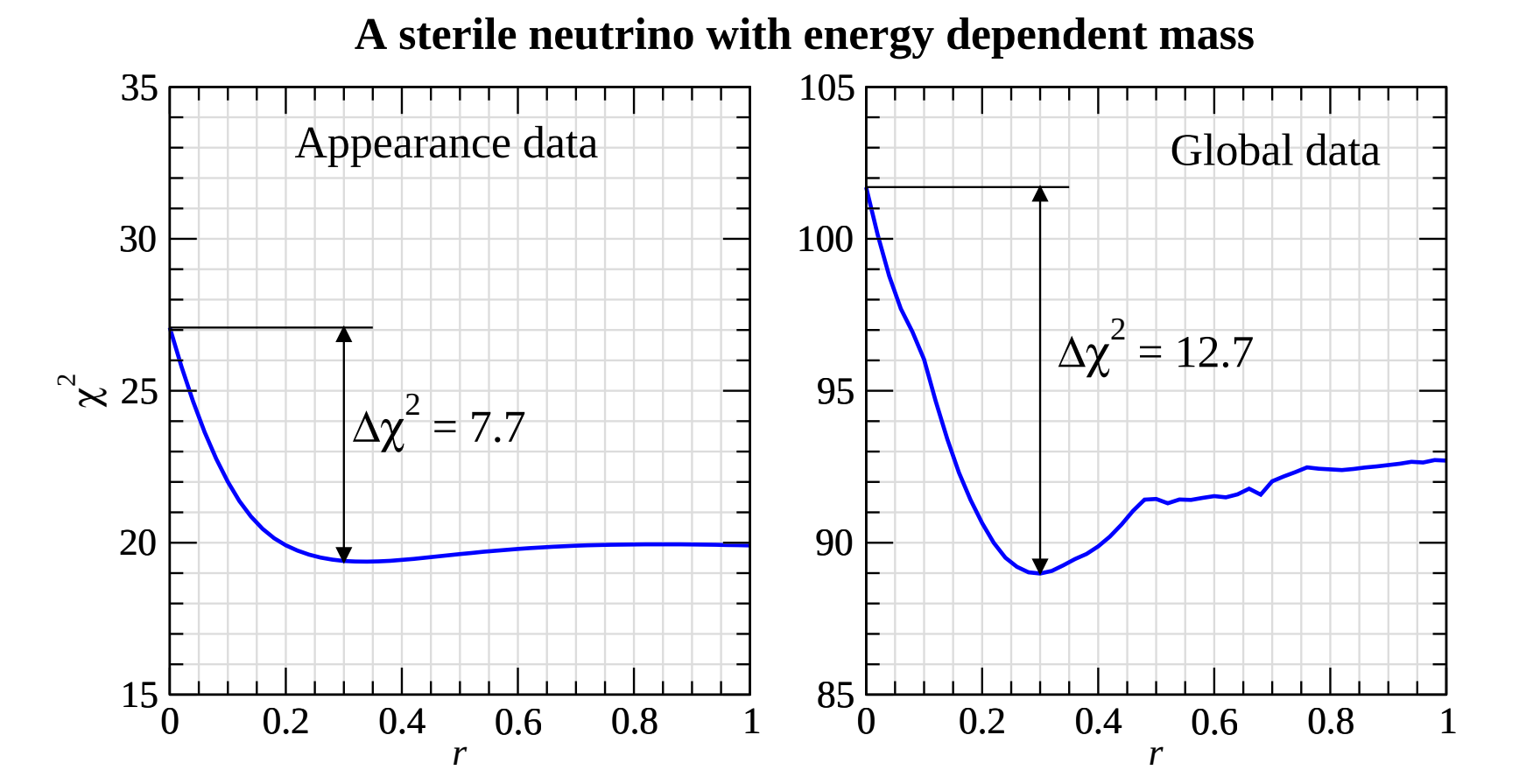

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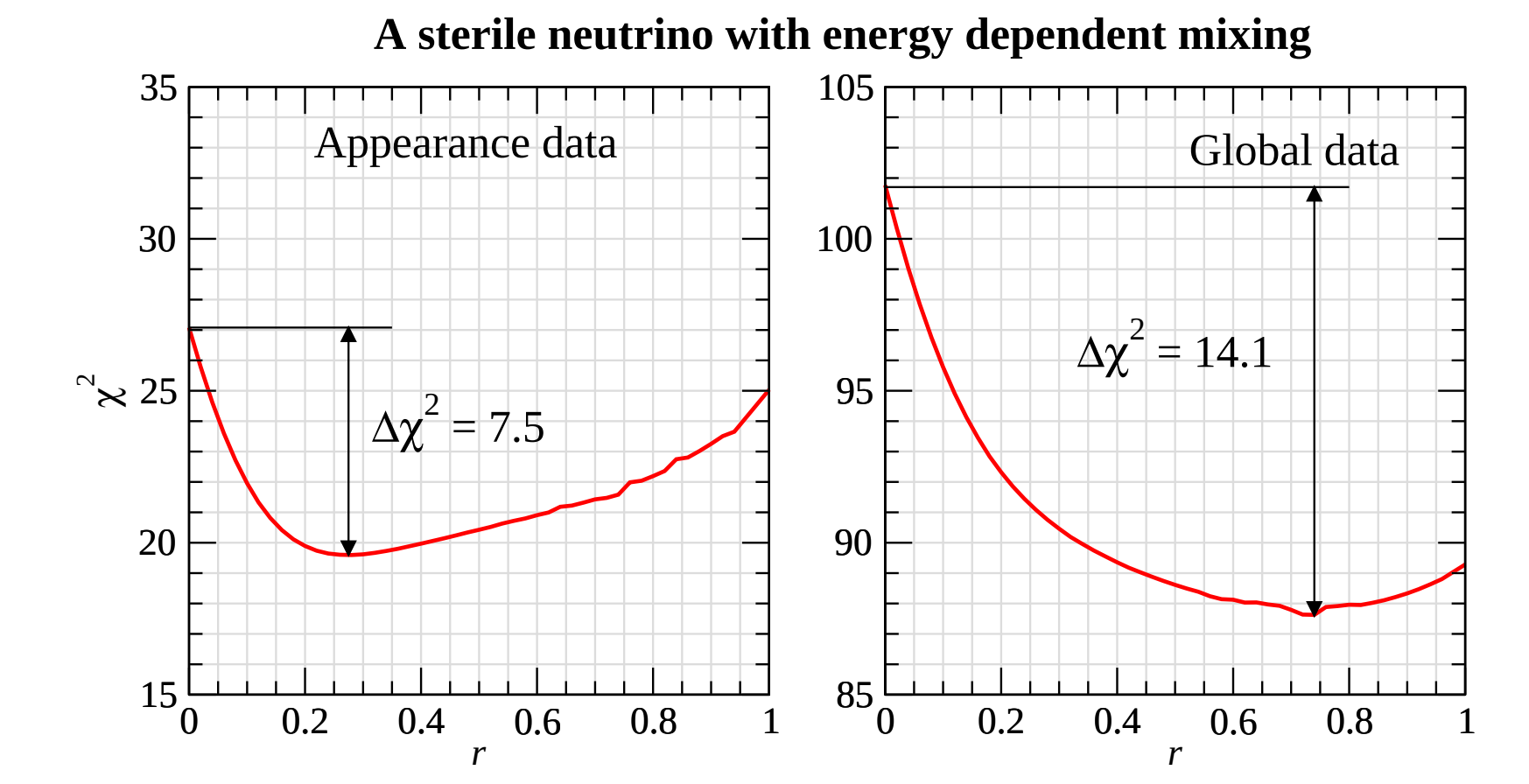

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- Many exotic physics models fail – sterile neutrino oscillations with an exotic energy dependence can fit all data (except the MB excess)

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- could be worth to look for disappearance at the $\Delta m^2 \sim 1\,\mathrm{eV}^2$ scale at future reactor or LBL experiments (near detectors)
- sterile neutrinos with $\Delta m^2 \sim 1\,\mathrm{eV}^2$ might lead to large effects for high energy atmospheric neutrinos in IceCube S. Choubey, 0709.1937